TIGHT BINDING BOOK

INSTRUCTIONS

IN

PHYSICAL MEASUREMENTS

MECHANICS, PROPERTIES OF MATTER, HEAT, MAGNETISM, ELECTRICITY, WAVE MOTION, SOUND AND LIGHT

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SECOND EDITION
SEVENTH PRINTING

NEW YORK
D. VAN NOSTRAND COMPANY, INC.
250 FOURTH AVENUE

First Published, August 1939
Second Edition, September 1940
Reprinted October 1942, June 1943, July 1943
December 1943, December 1944, July 1946

PRINTED IN U.S.A.
DEPENDABLE PRINTING COMPANY, INC.
NEW YORK, N. Y.

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THE ACCURACY OF PHYSICAL MEASUREMENTS

Every experiment is subject to a certain degree of accuracy which the student is expected to attain. Good results can always be obtained by following the instructions on the exercise sheet.

Rule A. In general, instruments should be read to the limits of their scales by estimating the last figure.

For example, when the scale of an ammeter is graduated in amperes, it is usually possible to estimate the tenths of a division. All observations and other data should be recorded before any calculations are made; i.e., do not record calculations for observations. By observations one means all quantities actually read on the instruments. Fractions should be reduced to the decimal form before recording. Do not retain more figures in the result than the precision of the data warrants. Students should form the habit at once of rejecting at each step of the work all figures which will have no influence on the reliability of the final result. Too much emphasis cannot be placed on the proper use of significant figures, for much time in computing is wasted because of the retention of more figures than the precision of the data will warrant. In most laboratory exercises not more than the first four significant figures of any result will be correct, and often not more than three, because the apparatus cannot be made to give more accurate results. It is not considered good form to retain more than one doubtful figure; so, in general, computed results should not contain more than five significant figures, the extra figure being retained to protect the correctness of the fourth figure in the result.

A significant figure is any digit used to denote the amount of the quantity in the decimal place in which the digit stands. Consider the reading c = 3.09 mf. All the figures are significant, including the zero. In c = 3.10 mf. the zero is again significant; since the value was nearer to 3.10 mf. than to 3.09 mf. or 3.11 mf. But in a value I =.05675 milliamperes, the zero is not significant, since the same current might have been written I = .00005675 amperes or I = 56.75 microamperes, all of which are correct to four significant figures although the nonsignificant zero has disappeared in the last way of writing the current. In rejecting superfluous figures in any result:

Rule B. In sums and differences no more decimal places should be retained than can be trusted in the quantity having fewest trustworthy decimal places.

Rule C. In products and quotients no more figures should be kept than can be trusted in the quantity having fewest trustworthy figures.

AVERAGES: When measurements of physical quantities are made in the laboratory absolute accuracy is not attained, as is evidenced by the small variations in the results that occur from different observations, even though they are made with great care and under most exacting conditions. Thus, every result, no matter how carefully it may have been obtained, has a certain probable error which depends upon the number of measurements made, their agreement and certain other factors. The errors of measurements fall into two general classes: systematic or constant errors, and erratic or accidental errors. Systematic errors may be due to imperfections in the apparatus, to faulty methods, or to prejudice of the observer. All those effects may be removed by study and care on the part of the observer. The accidental errors are as likely to be positive as negative. When several independent observations have been made with equal care the arithmetical mean of the observed values is the most probable value to be obtained: i.e., suppose "n" observations are made on the capacitance of a fixed condenser and call the separate observations $c_1, c_2, c_3, \ldots c_n$; then the best value of C is the arithmetical mean (average) or

$$C = \frac{1}{n}\sum_{1}^{n} c_n, \qquad (1)$$

which is as nearly as possible the value sought. If the quantity has a generally accepted value (T); then the error can be at once determined by subtracting C from T. The per cent of error then is

$$\text{Per cent } E = \frac{T - C}{T} \times 100 \qquad (2)$$

In case the true value of the quantity is not known, then the trustworthiness of the measurements may be determined by the "average deviation" (a.d.) test. The deviation (d) of any single observation is the difference between that observation and the average (c) for the set of observations. The "a.d." is the arithmetical mean of the deviations: i.e.,

$$\text{a.d.} = \frac{1}{n}\sum_{1}^{n} d_n, \qquad (3)$$

which is the amount by which any single observation might be expected to deviate from C.

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Observations, Drawings, Computations:

Answers and Conclusions:

Obviously the reliability of the mean value C is greater than that of any single observation and it may be shown by the Theorem of Least Squares to be $\sqrt{n}$ times more reliable. So the Average Deviation of the Mean (A.D.) is $\sqrt{1/n}$ times the average deviation of any single observation: i.e.,

$$A.D. = \frac{a.d.}{\sqrt{n}} \qquad (4)$$

One sees by this that the mean of four observations is only twice as reliable as a single observation; that the mean of nine observations is three times as reliable, etc. The above equation is the general test for trustworthiness, but it must be clearly understood <u>to apply to the erratic errors only</u>.

If the value found for a quantity a is 1 per cent too large, i.e., is 1.01a, then the value that will be obtained for a^2 is 1.0201a, which is about 2 per cent too large, and the value for a^3 is 1.03031a, which is about 3 per cent too large.

<u>Rule D.</u> In general, if the value found for a is k per cent too large, the value that will be obtained for a^n will be nk per cent too large. So that a quantity which is to be squared, cubed or raised to some higher power should be measured with more care than if it entered the formula to the first power.

When any of the quantities which are to be multiplied or divided can be trusted no closer than one per cent a slide rule can be used. Otherwise, more accurate methods should be used.

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Observations, Drawings, Computations:

Answers and Conclusions:

stick by 0.1 mm or 0.01 cm. Likewise the second vernier division will lack coincidence with the second meter stick division by 0.02 cm., etc., until the 10th division of the vernier which will lack coincidence with the 10th meter stick division by 1.mm. or it coincides exactly with the 9th division of the meter stick.

Conversely, if in making a measurement the 1st vernier division coincides with a division on the meter stick, then the zero mark of the vernier is 0.01 cm. beyond some division of the meter stick. In a similar manner, if the 7th vernier division coincides with a meter stick division, then the vernier zero will be 7(s/n) beyond some division of the meter stick, where s/n is the value of the least count (0.01 cm. in this case). Therefore, in general, if x is the number of the vernier division which coincides with a meter stick division, then the vernier zero will be x(s/n) beyond some division of the meter stick. It should be remembered that it must be determined how much the vernier zero lacks coincidence with a division on the meter stick. In Figure 2, on the preceding page, the reading is 1.14 cm.

If measurements are desired with an accuracy greater than that given by the vernier, the micrometer vernier is used. This instrument, shown in Figure 3, is usually made in a semi-circular form and has two "jaws" one of which is stationary and the other movable. The movable one is so arranged as to advance a certain distance for one complete revolution of the shaft by having cut on it a very accurate thread. Usually this distance is such that the movable jaw moves forward 1 mm. or 0.5 mm. for one complete revolution. So if the "drum" of the shaft is divided into an equal number of divisions, the fraction of a mm. (or 0.5 mm.) that the screw has moved can be found by reading the division on the drum which coincides with a mark on the shaft. This division of the drum is usually 100 equal parts, giving the smallest reading possible as 0.01 mm. or 0.001 cm. In case the drum is divided into 50 equal parts for an advance of 0.5 mm., then the smallest reading possible is 1/50 of 0.5 or again 0.01 mm. (0.001 cm.). However, in the case where the drum must rotate twice for an advance of one mm., care must be taken to note, in making a reading, whether the drum is on the first or second revolution beyond a mm. mark. If it is on the second, 0.5 mm. is to be added to the fractional reading.

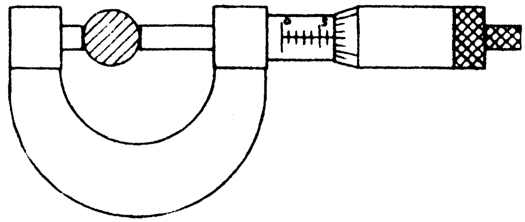

Figure 3

Experiment

Part 1

With the vernier caliper assigned, note the value of the smallest division on the main scale. Calculate the least count of the instrument as explained above. Measure the diameter of sample 1 with the vernier caliper at nine different places, being sure to displace and reset the caliper each time. Find the average diameter, and the average deviation as explained in "The Accuracy of Physical Measurements." Also measure the length of the sample. Make the same calculations as for the diameter.

Part 2

With the micrometer caliper assigned, note the smallest reading of which it is capable and find the zero correction, if any. Measure the diameter at nine different places, being sure to displace and reset the screw each time. Calculate the average diameter, and average deviation of the mean. With a vernier caliper measure the length of the sample. Make the same calculations as before.

Part 3

Using the data from Part 1 calculate the volume of the sample. In doing so observe rules B and C as given in "The Accuracy of Physical Measurements."

Calculate the average deviation of the mean (A.D.) for measurements made in Part 1.

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Observations, Drawings, Computations:

Answers and Conclusions:

TEST EXPERIMENT I

1. A certain vernier caliper has a.....divisions on its movable scale. These divisions are of the same length as b.....divisions on the main scale. If each division on the main scale is c..... inch, the least count is (1) , (2) , (3) , (4) . . ( )

2. The density of a solid is found to be a..... The true value is b..... The percentage error is (1) , (2) , (3) , (4) . . . . ( )

3. The least count on a certain vernier caliper, whose smallest division on the principal scale is a....mm. and whose smallest division on the vernier scale is b....mm. is (1) , (2) , (3) , (4) . . . . ( )

4. Following the rules for addition of significant figures, we should write a ....+b ....+c ....+d .... = (1) , (2) , (3) , (4) . . . . ( )

5. The length of a pendulum was determined by measuring the length of the support, a....cm., and adding to it the radius of the bob, b....cm. The length of the pendulum (in cm.) is (1) , (2) , (3) , (4) . . . . ( )

6. The result of multiplying two measured values a.... and b.... is (1) , (2) , (3) , (4) . . . . ( )

7. The diameter of a piston is measured as a....inches. The cross sectional area (in sq. in.) is (1) , (2) , (3) , (4) . . . . ( )

8. Five observations, a....cm., b....cm., c....cm., d....cm., and e....cm., are made in the measurement of a diameter. The most probable value of the diameter (in cm.) is (1) , (2) , (3) , (4) . . . . ( )

9. In the case of the preceding problem one checks on the trustworthiness of the observations by finding the average deviation, which is (in inches) (1) , (2) , (3) , (4) . . . ( )

10. On a certain barometer, the main scale has a....divisions per inch. The vernier scale is divided into b....parts and is c.... inches in length. The least count is (1) , (2) , (3) , (4) . . . . ( )

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Observations, Drawings, Computations:

Answers and Conclusions:

Experiment 2

FORCE AND ACCELERATED MOTION USING THE ATWOOD MACHINE

Object:

Observation of accelerated motion and a study of Newton's second law of motion.

Apparatus:

A mounted pulley, cord, weights to be suspended, and a stop watch to be used in measuring the time intervals.

Theory:

The motion of a freely falling body is the most direct example of uniformly accelerated motion. The equation of motion for such a body is

$$W = mg \qquad (1)$$

where W = the weight or force of gravity, m = the mass of the body, g = the acceleration. As g is a rather large acceleration, the velocity increases very rapidly and measurements are difficult.

Since the purpose of this experiment is to learn the use of Newton's law

$$F = ma, \qquad (2)$$

of which equation (1) is a special example, it is important that the acceleration be small enough so that reasonably accurate measurements of distances the body travels in given units of time can be made.

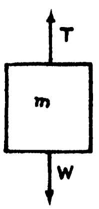

Figure 1

If a string is attached to a body that pulls upward on it with a tension T and this is just equal to the weight (see Figure 1), then the force equation is

$$W = T \text{ or } W - T = 0.$$

If T is made a little less than W (see Figure 2), the equation of forces is

$$W - T = F, \qquad (3)$$

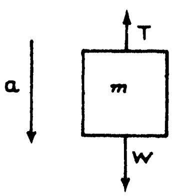

Figure 2

where F is the remaining or unbalanced force that causes motion. By combining equations (2) and (3) one gets

$$W - T = ma. \qquad (4)$$

This last equation shows that theoretically the acceleration a can be made as small as desired by making W and T more nearly equal to each other.

Suppose a string is placed over a pulley and two masses m_1 and m_2 are attached to the ends of the string as in Figure 3. This is a device in which both the forces of tension and gravity act and it is called the Atwood machine. If m_1 is greater than m_2 motion will occur and the pulley will turn in the direction indicated by the arrow.

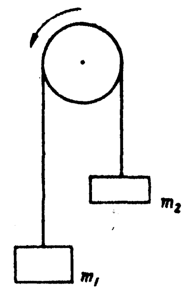

Figure 3

From Figure 2 and equation (4) the equations of motion of the masses in Figure 3 can be written immediately.

The motion of m_1 is given by

$$W_1 - T_1 = m_1 a_1$$

and of m_2 by

$$W_2 - T_2 = m_2 a_2 \qquad (5)$$

Since the masses m_1 and m_2 and the string form a complete system, the two above equations are not independent of each other. If the string remains the same length, then the motions of the two bodies must be equal in magnitude. However, they move in opposite directions, so

$$a_1 = -a_2 = a. \qquad (6)$$

Another simplification is possible if it is assumed that the string is very light and flexible and also that the pulley is very light and rolls so freely in its bearings that the effects of these factors on the motion can be neglected, then

$$T_1 = T_2 = T. \qquad (7)$$

On substituting equations (6) and (7) in equation (5) they become

$$W_1 - T = m_1 a$$

$$W_2 - T = -m_2 a,$$

and substraction of these gives

$$W_1 - W_2 = (m_1 + m_2)a.$$

Therefore $$a = \frac{W_1 - W_2}{m_1 + m_2} = \frac{F}{M},$$

and, making use of equation (1), the acceleration may be expressed

$$a = \frac{m_1 - m_2}{m_1 + m_2} g = \frac{F}{M}. \qquad (8)$$

Equation (8) shows that the acceleration varies directly as the unbalanced force F and inversely as the total mass M.

The acceleration can be found by another method because the fundamental definition of acceleration is rate of change of velocity, or in symbols:

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Answers and Conclusions:

$$a = \frac{v_f - v_o}{t} , \tag{9}$$

where v_o = the initial velocity, v_f = the final velocity, t = the time during which the change is taking place.

The quantities that can be measured directly are distance and time. The definition of distance traveled is

$$s = 1/2(v_o + v_f)\ t. \tag{10}$$

Elimination of v_f between equations (9) and (10) gives

$$s = v_o t + 1/2\ at^2 . \tag{11}$$

Furthermore, if the initial velocity is zero, then

$$s = 1/2\ at^2 ,$$

whence

$$a = \frac{2s}{t^2} . \tag{12}$$

Equations (8) and (12) are both measures of the same acceleration; therefore they should give the same result. The distance s traveled can be measured quite accurately, so the only source of appreciable error in equation (12) arises in the measurement of the time.

All the quantities in equation (8) may be obtained with great accuracy since weighing can be performed with high precision and the correct value of g may be obtained from tables. The only source of error that can affect equation (8) comes from the assumption that

$$T_1 = T_2 .$$

This implies that the effect of the string and the pulley is zero, which is not strictly true. If the string and pulley are very light in weight, the only remaining error is the friction in the pulley bearings. This can be compensated for by adding a small additional weight to the end of the string that moves downward. Small weights of 1 gm. or 1/2 gm. each are provided for this purpose. Enough of these are added to m_1 so that the weights will move with uniform velocity when once started. When this is done the effect of friction is practically eliminated and equation (8) becomes

$$a = \frac{m_1 - m_2}{m_f + m_1 + m_2} g, \tag{13}$$

where m_f = additional weight to overcome friction.

Equations (12) and (13) are to be used in the experiment. The former gives what is called the observed acceleration and is denoted by a_o , the latter gives the theoretical acceleration and is denoted by a_t. The reason for these names is that a_o is determined by actual observations of motion, while a_t is calculated directly from Newton's law, by using the constants of the machine.

Experiment

Part 1

Vary the force and keep the total mass constant.

Let $m_1 = m_2$ and let $m_1 + m_2$ = about 175 or 180 gms. and adjust m_f until the motion is uniform. Remove a 2 or 2 1/2 gm. weight from m_2 and place on m_1 The accelerating force will then be 4 or 5 gm. Raise the heavier weight to the starting position and then release it. Determine the time that it takes to fall 1 meter. Next find the time that it takes to fall 2 meters. Record your results in a table similar to the following:

					1 meter			2 meters		
$m_1 - m_2$	F	m_1+m_2	m_f	a_t	s	t	a_o	s	t	a_o

Next transfer another 2 (or 2 1/2) gm. weight from m_2 to m_1 so that the accelerating force is 8 (or 10) gm. Determine the time that it takes to fall 1 and 2 meters respectively. Continue recording the results.

Transfer one or more 2 (or 2 1/2) gm. weight and observe the time that it takes to fall 1 and 2 meters.

Having taken this data calculate and compare the accelerations.

In what way do these results confirm equation (8)?

Part 2

Vary the total mass and keep the force constant.

In this case the weight added to correct for friction will likely need to be adjusted each time the mass is changed. Let $m_1 - m_2$ = about 5 gm. thruout this part. For $m_1 + m_2$ = about 115 gm. observe the time that it takes to fall 1 and 2 meters respectively. Second let $m_1 + m_2$ = about 165 gm. and observe the time that it takes to fall 1 and 2 meters respectively.

Record all the data and calculate the accelerations.

In what way do these results confirm equation (8)?

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Observations, Drawings, Computations: ______________________

Answers and Conclusions: ______________________

TEST EXPERIMENT 2

1. A man on a bicycle starts from the top of a hill with a speed of a....ft. per second and undergoes an acceleration of b....ft. per second^2. During the third second he travels (in ft.)
(1) , (2) , (3) , (4) . . . . ( )

2. The a....lb. hammer of a pile driver falls freely for b....sec. before striking the pile. The velocity at impact in ft./sec. is
(1) , (2) , (3) , (4) . . . . ( )

3. An elevator weighing a....lb. has a downward acceleration of b....ft./sec.^{2}. The tension (in lb.) on the elevator cable is
(1) , (2) , (3) , (4) , ... ( )

4. Two masses of a....gm. each are connected by a light cord and hung over a frictionless pulley. If a b....gm. mass is added to one side, the acceleration of the system is (in cm. per sec.^{2})
(1) , (2) , (3) , (4) , ... ( )

5. A force F of a....dynes is pulling a wooden block along a horizontal surface against a retarding force of b....dynes. If the mass of the block is c....gms., its acceleration is (in cm. per sec.^{2})
(1) , (2) , (3) , (4) . . . . ( )

6. The height of an airplane from which a bomb fell to earth in a....sec. (neglect air resistance on the bomb) (in ft.) was
(1) , (2) , (3) , (4) . . . . ( )

7. A body will fall (in feet) from rest during the first a.... seconds (1) , (2) , (3) , (4) . . . . ( )

8. A body is thrown upward with a velocity of a....ft./sec. The time (in sec.) it takes to rise is (1) , (2) , (3) ,
(4) . . . . ( )

9. A mass of a....gm. is pulled along a horizontal surface with a uniform velocity by a cord attached to a mass of b....gm. which is suspended vertically by means of a pulley at the edge of the surface. The weight of b....gm. would produce an acceleration (in cm./sec.^{2}) of (1) , (2) , (3) , (4) . . . ( )

10. The velocity with which a stone must be thrown into a well a....ft. deep to reach bottom in b....sec. is (in feet per sec) ,
(1) , (2) , (3) , (4) . . . . ( )

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Observations, Drawings, Computations:

Answers and Conclusions:

Experiment 3

FRICTION

Object:

To study the laws of dry friction, and to determine the static and kinetic coefficients of friction for clean dry surfaces.

Apparatus:

Inclined plane, made for pulley to fasten at either end, wooden block, weights, pulleys, scale pan and a proctractor (if there is not one on the plane).

Theory:

When a body such as a block rests on any plane surface it takes a certain minimum force, F_p, applied parallel to the plane, to start the body sliding. Since one can apply a force f_s less than this minimum force F_p and the block stays in equilibrium, there must be another force tending to keep it in equilibrium. This force will be exactly equal in magnitude but opposite in direction to the applied force, and when the block is just on the point of slipping this reaction force is called the force of static friction. Now if one keeps the block sliding along the plane at constant velocity (state of equilibrium), one must again apply a certain force, f_k, parallel to the plane in order that the block move with constant velocity. Since it is in a state of equilibrium there must be another force which is equal in magnitude and opposite in direction to the applied force. This reaction force is called the force of kinetic friction.

At once several questions arise. How great are these forces of static and kinetic friction if the block is 2, 3, n times as heavy as before, all other conditions being the same? How great are these forces of static and kinetic friction if the block is laid on its side, thus giving a larger or smaller surface of contact with the plane? How does the force of kinetic friction vary with different velocities? These questions are answered by experimental tests and the results formulated into what are called the Laws of Dry Friction.

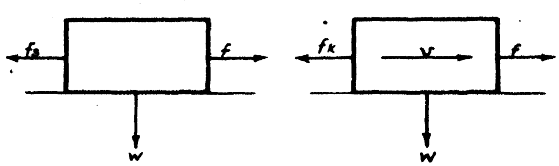

Figure 1

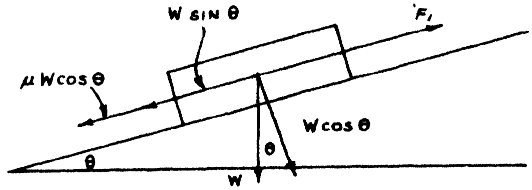

Figure 2

As to the first question, one knows from experience that the least force, f_s, necessary just to move the block is a definite fraction of the normal force, N, pressing the block and plane together. Denoting this fraction by μ, one can write

$$f_s = \mu N.$$

μ will have a definite value for every possible pair of surfaces and is known as the coefficient of static friction for these two surfaces. As to the second question, one knows that the force of friction is independent of the area of contact. It is also known that once the body is set in motion, the minimum force necessary to keep it sliding with constant velocity is a certain fraction of the force normal, N; so one can write

$$f_k = bN,$$

where b is called the coefficient of kinetic friction. This proportionality does not hold strictly for very small or very large velocities, but for moderate velocities b has a definite value for every possible pair of surfaces.

When the block rests on an inclined plane of angle θ, its weight can be resolved into two components as shown in Figure 2. The component W sin θ acts parallel to the plane and tends to make the body slide downwards, while the component W cos θ acts normal to the plane and presses the block to the plane with this force. This normal force in turn results in a force of friction parallel to the plane, but its direction of application is upwards.

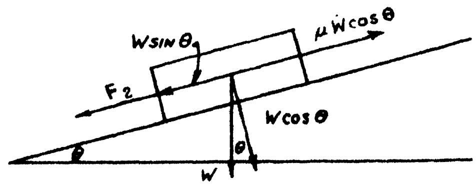

Figure 3

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Observations, Drawings, Computations:

Answers and Conclusions:

If the block is about to slip, this force of friction has a magnitude $\mu W \cos \theta$. If the block is moving with uniform velocity the magnitude is $bW \cos \theta$. In addition to these two forces parallel to the plane, one may apply either F_1 upwards or F_2 downwards. With these things in mind and remembering that the force of friction always opposes the motion of the block, one may write the following equations for four possible cases that may arise:

(a) The force F_1 that is just necessary to start the body sliding up the plane is

$$F_1 = W \sin \theta + \mu W \cos \theta, \tag{1}$$

for in this case F_1 must overcome static friction and the downward component of the weight.

(b) The force F_2 that is just necessary to start the block sliding down the plane is

$$F_2 + W \sin \theta = \mu W \cos \theta, \tag{2}$$

for in this case the weight helps to overcome friction.

(c) The force F_1 that will keep the block sliding up the plane with constant velocity is

$$F_1 = W \sin \theta + bW \cos \theta. \tag{3}$$

(d) The force F_2 that will keep the block sliding down the plane with constant velocity is

$$F_2 + W \sin \theta = bW \cos \theta. \tag{4}$$

It is a matter of common experience that if the angle θ is increased sufficiently the block will begin to slide down the plane without any force F being applied. This occurs when $W \sin \theta$ becomes just large enough to overcome the static friction force $\mu W \cos \theta$. This angle is called the limiting angle of static friction and is given by

$$W \sin \theta = \mu W \cos \theta$$
$$\mu = \tan \theta. \tag{5}$$

Similarly, the limiting angle of kinetic friction is the angle such that the block will continue to slide with constant velocity once started.

$$b = \tan \theta. \tag{6}$$

Experiment

Part 1

With block on the level plane put enough weights on the scale pan so that the block just starts to slide. Note the value of the weights and weight of the pan. Repeat three times. Weigh the block.

Lay the block on its side and repeat the experiment. Put weights equal to the weight of the block on the block and repeat. Using equation (1), calculate the coefficient of static friction. To what conclusions do you arrive?

With the block on the plane (inclined) (pulley at bottom end) put weights on the scale pan so as to make the block just start to slide down the plane. Repeat three times. Measure the angle of inclination and calculate the coefficient of static friction by equation (2).

With the block on the plane (pulley at top end) put enough weights on the scale pan so that the block just starts to slide up the plane. Note the value of the weights and repeat three times. Measure the angle of inclination of the plane. Compute μ.

Part 2

With the block resting on the plane (inclined) (pulley at top end) put enough weights on scale pan so that the block slides up with constant velocity once started. Repeat three times. Using equation (3) calculate the coefficient of kinetic friction.

With the block on a plane (pulley at bottom end) put enough weights on the scale pan so that the block slides down the plane with constant velocity once started. Repeat three times. Using equation (4) calculate the coefficient of kinetic friction.

Part 3

(a) Adjust the plane so that the block just starts to slide down. Note the angle of inclination of the plane. Repeat three times. Using equation (5) calculate the coefficient of static friction.

Record all date in a suitable manner so as to be able to compare the results.

Name: Instructor: Division: Date.

Observations, Drawings, Computations:

Answers and Conclusions:

TEST EXPERIMENT 3

1. An ax is pressed against a grindstone with a force of a.... lb. If the radius of the grindstone is b....ft. and the coefficient of static friction c...., then the starting torque* of the grindstone (in lb. ft.) is (1) , (2) , (3) , (4) , ... ( )

2. The coefficient of kinetic friction of iron on ice is 0.16. A boy is able to exert a pull of a....lbs. in a horizontol direction. The greatest load that he can move by the use of a sled with iron runners (in lb.) is (1) , (2) , (3) , (4) . ( )

3. It requires a force of a....lb. parallel to the surface of a plane to pull a b....lb. box up the plane when inclined c....deg. to the horizontal. The coefficient of kinetic friction is (1) , (2) , (3) , (4) . . . . ( )

4. The force required to keep a a....lb. box sliding down a b.... deg. plane at a uniform velocity, with the coefficient of kinetic friction being c...., is (in lb.) (1) , (2) , (3) , (4) . . . . ( )

5. A block of mass a....gm. is being pulled along a rough horizontal surface by a force equal to b....dynes. Its acceleration is c....cm./sec.^{2}. The retarding force of friction (in dynes) is (1) , (2) , (3) , (4) . . . . ( )

6. A force of a....lb. was necessary to slide a b....lb. box up an incline c....ft. long and d....ft. high at the upper end. The force of friction (in lb.) is (1) , (2) , (3) , (4) . . . . ( )

7. A sled slides down a plane inclined at an angle whose sine is a....and cos is b....with an acceleration of c....ft./sec.^{2}. The coefficient of kinetic friction is (1) , (2) , (3) , (4) . . . . ( )

8. The force of friction necessary to bring to rest a mass of a.... gm. in a space of b....cm., if the initial horizontal velocity of the body is c....cm./sec., is (in dynes) (1) , (2) , (3) , (4) . . . . ( )

9. It requires a force of a....lb. parallel to the surface of a plane to pull a b....lb. box up an inclined plane, and a force of c....lb. is required to let the box slide down with a uniform velocity. The frictional force (in lb.) is (1) , (2) , (3) , (4) . . . . ( )

10. The coefficient of kinetic friction between a block and a table is a..... The force required to keep a b....gm. block in uniform motion (in dynes) is (1) , (2) , (3) , (4) . . . ( )

*(frictional force x radius)

Name: Instructor: Division: Date.

Observations, Drawings, Computations:

Answers and Conclusions:

Experiment 4

CENTRIPETAL FORCE

Object:

To verify experimentally the centripetal force due to circular motion as deduced from theory.

Apparatus:

Rectangular frame with suspended bob, two springs, spring balance, meter stick, calipers, and stop watch.

Theory:

Uniform circular motion is a motion in a circular path with a constant speed. Since the direction of the motion is continually changing, the velocity of the body is changing at every point in its path. This means that the body is subject to an acceleration. In calculating this acceleration, it is convenient to regard the circular path as being made up of a large number of very short arcs and then to resolve the motion

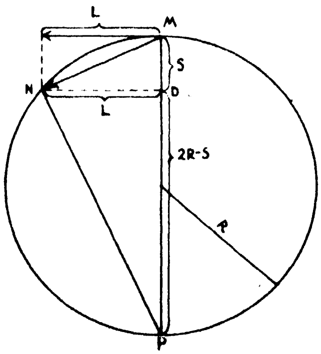

Figure I

of the body along any of these arcs into two components, one component being uniform motion tangent to the circle and the other being accelerated motion toward the center of the circle. See Figure I. Assume that a body at M moves at constant speed V around a circle of radius R and that during a short time interval t it follows the arc to some point N. In the diagram MN is drawn large for the sake of clearness, but actually it is taken to be so small that arc MN practically coincides with chord MN. The chord is resolved into components L and S, tangential and perpendicular to the motion at M. So in going from M to N, the body may be considered as moving a distance L with the constant speed V and simultaneously moving a distance S with a constant acceleration A.

From the equations of linear motion:

(1) $L = V\,t \quad , \quad S = 1/2\ At^2 .$

Triangles MND and NPD are similar, so:

$$\frac{S}{L} = \frac{L}{2R - S} .$$

But as the arc MN becomes smaller, the length 2R-S approaches the value 2R. Hence for a very short arc:

$$\frac{S}{L} = \frac{L}{2R} .$$

Substitute the expressions of equation (1) for L and S:

$$\frac{(1/2\ At^2)}{V\,t} = \frac{V\,t}{2R} \quad \text{, or}$$

(2) $$A = \frac{V^2}{R} .$$

This is the expression for the acceleration of the body toward the center.

From Newton's Second Law of Motion one finds the centripetal force acting upon a body of mass m moving with uniform circular motion. Newton's law:

$$F = m\,A .$$

For A substitute the value given in equation (2). Then the centripetal force is given by:

(3) $$F = \frac{m\,V^2}{R} .$$

The period T of the motion is the time of one complete rotation. In each rotation the angular displacement is 2π radians. Hence the constant angular velocity ω is given by:

(4) $$\omega = \frac{2\pi}{T} .$$

The angular velocity is also given by:

$$\omega = \frac{V}{R} .$$

From the above equation and equation (4), one can obtain other expressions for V, A, and F.

(5) $$V = \omega R = \frac{2\pi R}{T} ,$$

(6) $$A = \frac{V^2}{R} = \frac{4\pi^2 R}{T^2} ,$$

(7) $$F = mA = \frac{4\pi^2 mR}{T^2} .$$

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Observations, Drawings, Computations: ______

Answers and Conclusions: ______

The quantities m, R, and T will be measured directly and the force F will be obtained by an application of Hooke's Law, which states that the stretch of a spring is directly proportional (within the elastic limit) to the force applied to it.

Experiment A

The apparatus is set up as in Figure 2. A vertical rod rotates on bearings between the horizontal bars of a rectangular frame. Near the top of this rod is fixed a horizontal rod H. A short horizontal rod is fixed to H so as to form a T. A heavy metal bob is hung from this short rod by a bifilar suspension. A helical spring S is fastened to the bob and the vertical rod. A pointer is attached to the bottom of the bob, and another pointer is placed on the lower cross bar of the supporting stand.

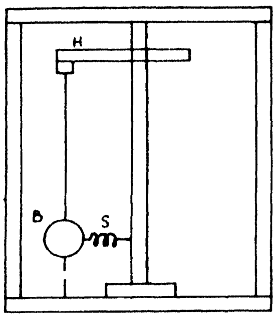

Figure 2

Twist the vertical rod between the fingers, thus causing the bob to rotate. The bob will swing out until the tension in the spring is sufficiently great to produce the necessary centripetal force. If the tension of the spring is equal to the required centripetal force, the bob will rotate with uniform circular motion. Twist the vertical rod at such a rate that the pointer on the bob swings just over the pointer on the frame. Make sure that the spring S is horizontal. Keep the speed as nearly uniform as possible. Observe the time for twenty rotations. Repeat this five times (do not change position of pointer). From this set of observations, determine T, the time of one rotation. Measure R, the distance from the axis of rotation to the center of mass of the bob, that is, the distance from the axis of rotation to the pointer on the frame. Weigh the bob with a spring balance in order to obtain its mass, m. Substitute these measured values of T, R, and m into equation (7) and calculate F, the centripetal force exerted on the bob by the spring.

The force exerted by the spring may be found by a spring balance. Measure this force when the bob is pulled out by the balance so that the two pointers coincide. This value of the force should be the same as the calculated value of the centripetal force. Calculate the percentage error.

Change the tension in the spring and repeat all measurements and calculations.

Calculate the centripetal acceleration A, the linear speed V, and the angular velocity ω for each case.

Experiment B

Apparatus:

Stop watch and Centripetal force apparatus with rotator. In this experiment the apparatus is fastened (with its axis of rotation in a vertical position) in some form of rotator with variable speed.

The apparatus is represented in Figure 3. A cylindrical mass M, free to slide on guide rods, is fastened to a spring. The tension of this spring is adjustable by means of a screw S, the setting of which is indicated by means of a scale fastened to the frame. The entire apparatus is mounted in a rotator socket. A pointer P attached to the mass indicates its position.

For a given tension (i.e. a given setting of the screw S) adjust the speed of rotation so that the mass M moves out until the pointer comes to a predetermined position. Keeping the speed as nearly uniform as possible, observe the time for twenty rotations. Repeat this observation five times (for the same tension and same pointer position). From this set of observations find T, the time of one rotation. Measure R, the distance from the axis of rotation to the center of mass of the cylinder (when pulled out to its rotation position). Substitute the measured values of T and R and the given value of the mass, m, into equation (7), and calculate F, the centripetal force exerted on the cylinder by the spring.

This force F can be found by hanging the apparatus in a vertical position, attaching a weight holder to the lower end of M and adding weights until the spring is stretched by the same amount as during rotation. Then F is given by the added weight plus the weight of M. This value of the force should be the same as the calculated value of the centripetal force. Calculate the percentage error.

Change the tension in the spring (by changing the setting of the Screw S) and repeat all measurements and calculations.

Calculate the centripetal acceleration A, the linear speed V, and the angular velocity ω for each case.

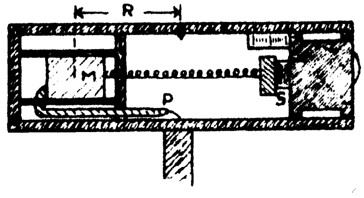

Figure 3

Name: ____________ Instructor: ____________ Division: ________ Date. ________

Observations, Drawings, Computations:

Answers and Conclusions:

TEST EXPERIMENT 4

1. A body of mass a....gm. is moving in a circular path of radius b....cm. with a linear speed of c.....cm./sec. The centripetal force (in dynes) must be (1) , (2) , (3) , (4) . . ( )

2. A body of mass a....gm. is rotating in a circle of radius b....cm. at the rate of c....rev. p. sec. The centripetal force (in dynes) is (1) , (2) , (3) , (4) . . . . ( )

3. A body of mass a....lb. moves in a circular path of radius b....ft. with a linear speed of c....ft./sec. The centripetal acceleration (in ft./sec.^{2}) is (1) , (2) , (3) , (4) . ( )

4. The centripetal force acting upon the body of problem (3) is (in lb.) (1) , (2) , (3) , (4) . . . . ( )

5. A body of mass a....gm. moves in a circular path with radius b....cm. with a period of c....sec. The centripetal acceleration (in cm./sec.^{2}) is (1) , (2) , (3) , (4) . . . . . ( )

6. The centripetal force acting upon the body of problem (5) is (in gm.) (1) , (2) , (3) , (4) . . . . ( )

7. A heavy ball is whirled in a vertical circle of radius a....ft. In order for the cord to be taut when the ball is at the highest point, the least linear velocity (in ft./sec.) must be (1) , (2) , (3) , (4) . . . . ( )

8. A boy weighing a....lbs. sits on a rotating platform at a distance of b....ft. from the axis. The force of friction is c.... lb. The angular velocity (in rad./sec.) which will make the boy slide off is (1) , (2) , (3) , (4) . . . . ( )

9. Two bodies A and B are located at distances of a.... and b.... cm. respectively from an axis. Both bodies rotate about the axis with the same angular velocity. The ratio of the centripetal acceleration of B to the centripetal acceleration of A is (1) , (2) , (3) , (4) . . . . ( )

10. A given cord a....ft. long can withstand a tension of b....lb. The weight of the heaviest body that can be whirled at the end of this cord at a rate of c....rev. p. sec. is (in. lb.) (1) , (2) , (3) , (4) . . . . ( )

Name: ______ Instructor: ______ Division: ______ Date. ______

Observations, Drawings, Computations:

Answers and Conclusions:

Experiment 5

MOMENT OF INERTIA AND RADIUS OF GYRATION

Object:

To give the student some experience in quantitative measurements dealing with angular motion by determining the moment of inertia of a wheel and axle from measurements of the torque required to accelerate it and of the resultant angular acceleration.

Apparatus:

Wheel and axle, pulley and cord, small weights, calipers, meter stick. The Atwood's machine of Expt. 2 can be used by substituting the wheel and axle for the light mounted pulley.

Theory:

The angular acceleration given to a rotating body by a torque T is expressed by:

(1) $T = I\alpha$, where T = torque in dyne-cm,
I = moment of inertia of rotating body in gm-cm^2,
α = angular acceleration in rad/sec^2.

Hence, if T and α are found experimentally, I may be calculated from equation (1).

K, the radius of gyration, is defined by:

(2) $I = mk^2$,

where I = moment of inertia,
m = mass in gm.
K = radius of gyration in cm.

So, once I is determined by equation (1), K may be found from equation (2).

In this experiment the rotating body is a wheel and axle (see Fig. 1) for which the masses are known and the radii may easily be measured. For a wheel and axle, the moment of inertia is:

(3) $$I = \frac{M_2}{2}\left[r_2^2 + r_3^2\right] + \frac{M_1}{2}\, r_1^2 ,$$

where M_1 = mass of axle,
M_2 = mass of wheel,
r_1 = radius of axle,
r_2 = radius of wheel (outer),
r_3 = radius of wheel (inner).

In equation (2) m denotes the total mass. Hence, for the wheel and axle, the radius of gyration is given by:

(4) $I = (M_1 + M_2)\ K^2$.

In the experiment measurements will be made so that I may be found from equation (1) and then checked by the theoretical expression of equation (3). For any value of I, the corresponding value of K is given by equation (4)

Experiment

Part I

To measure the torque T and the acceleration α proceed as follows:

The apparatus is assembled as in Figure 1. Start with a small mass for M_0, but with the mass M not attached. Increase or decrease the amount of mass M_0 until it goes down at constant speed after it has been started. This partially corrects for the frictional resistance.

Next, attach a 200 gm. mass M to M_0, wind up the cord on the axle and let M_0 rest on a support at position A. Release the support and let the cord unwind.

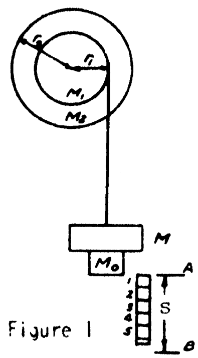

Figure 1

Place a support at a lower point B such that the mass M will travel 1 meter. Observe the time that it takes the mass to reach the point B. Repeat the operation by adjusting the point B so that the mass falls 2 meters. Tabulate the distances s and times t just measured.

The angular acceleration α can be found from the linear acceleration, a, by the relation

$$\alpha = \frac{a}{r_1}.$$

The linear acceleration, a, can be found from the relation

$$s = (1/2)\, at^2 .$$

Combining these equations, one gets

$$\alpha = \frac{2s}{r_1\, t^2}.$$

Calculate a for each distance s and get an average value (since it should be constant). Then calculate α using the average "a", The tension P in the cord can be found from the force equation:

$$(M + M_0)\, g - P = (M + M_0)\, a.$$

After finding P, one can calculate the torque T from the relation:

$$T = Pr_1 - M_0\, gr_1 .$$

Name: ______ Instructor: ______ Division: ______ Date. ______

Observations, Drawings, Computations:

Answers and Conclusions:

Combining these equations one gets

$$T = r_1 \ (M + M_0) \ (g - a) - M_0 g r_1.$$

Calculate T using the average value of "a" found above. It remains only to find I and K from the relations (1) and (4).

The values of the masses M_1 and M_2 are stamped on the wheel and axle. The radii r_1 and r_2 are to be measured with calipers and a meter stick. The distances should be measured in centimeters.

Part 2

Find the theoretical values of the moment of inertia and the radius of gyration of a wheel and axle by calculations based upon equations (3) and (4).

Find the per cent error in your experimental value found above.

In conclusion, discuss the cause of the large errors involved.

Name: ________ Instructor: ________ Division: ________ Date. ________

Observations, Drawings, Computations:

Answers and Conclusions:

TEST EXPERIMENT 5

1. A wheel rotates a....revolutions in b....seconds. Its average angular velocity (in rad./sec.) is (1) , (2) , (3) , (4) , ... ( )

2. The torque applied to a wheel of diameter a....ft. is b....lb. ft. If the force producing the torque is applied tangentially to the circumference, it is (in lb.) (1) , (2) , (3) , (4) ( )

3. The radius of a disc is a....cm. and its weight is b....gm. Its moment of inertia (in gm. cm.^{2}) is (1) , (2) , (3) , (4) . . . . ( )

4. A tangential force of a....lb. is applied to a cylinder b....ft. in diameter. The torque (in lb. ft.) is (1) , (2) , (3) , (4) . . . . ( )

5. The linear acceleration of a body attached to the end of a cord which is being wrapped around a cylinder of a....cm. radius is b....cm./sec.^{2}. The angular acceleration of the cylinder (in rad./sec.^{2}) is (1) , (2) , (3) , (4) . . . . ( )

6. An engine flywheel is making a....revolutions per second when the steam is shut off. If it comes to rest with constant deceleration in b....seconds, it will make (1) , (2) , (3) , (4) revolutions . . . . ( )

7. A force of a....lb. is pulling on a cord which is wound around the axle of a wheel. If the moment of inertia of wheel and axle is b....(w/g) ft.^{2} and the angular acceleration is c....rad./sec.^{2}, the radius of the axle (in ft.) is (1) , (2) , (3) , (4) . . . . ( )

8. A point on the rim of a wheel a....feet in diameter has a linear acceleration of b....ft./sec.^{2}. The angular acceleration of the wheel (in rad./sec.^{2}) is (1) , (2) , (3) , (4) . . . . ( )

9. A torque of a....dyne-cm. is applied to a body whose moment of inertia is b....gm.cm.^{2}. The resultant angular acceleration (in rad./sec.^{2}) is (1) , (2) , (3) , (4) . . . ( )

10. A torque of a....lb. ft. is applied to a body initially at rest whose moment of inertia is b....(w/g) ft.^{2}. If we neglect friction, the resulting angular acceleration is (in rad./sec.^{2}) (1) , (2) , (3) , (4) . . . . ( )

Name: Instructor: Division: Date.

Observations, Drawings, Computations:

Answers and Conclusions:

Experiment 6

APPLICATION OF THE THEOREM OF MOMENTS IN THE STUDY OF THE SENSITIVITY OF THE BALANCE

Object:

To verify experimentally the sensitivity of a balance as calculated from the theorem of moments.

Apparatus:

Model balance, 10 gm. wt., 2-200 gm. wts., meter stick.

Theory:

A force acting upon a body produces a rotation of the body if the line of action of the force does not pass through the center of mass of the body. The effect of a force depends not only on the magnitude of the force but also on the perpendicular distance between the line of action of the force and the axis of rotation. In Figure I, if the distances OA and OB are equal and if $F_1 = F_2$, then no motion of the rod AB occurs because

$$\overline{OA}\,(F_1) - \overline{OB}\,(F_2) = 0.$$

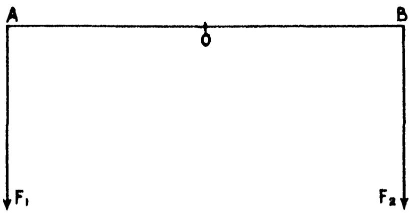

Figure I

The balance is an application of this principle. Usually the arms of a balance are equal, and when equal masses are placed on the scale pans, gravity exerts the same downward pull on each. By attaching a pointer to the beam at O, one can tell when the masses are equal by noting the direction of the pointer. The pointer is vertical for equal masses and an inclination of the pointer shows that one mass is greater than the other.

In using a balance it is important to know how sensitive it is to small differences of load on one of the pans. It is obvious that one can not measure the mass of an object to the nearest milligram on a balance which shows no motion of the pointer for an addition of 10 milligrams to one pan. It is also important to know how the sensitivity depends upon the load. An expression for sensitivity will be derived which shows what factors determine sensitivity, and calculated results will be checked in the experiment.

Figure 2 is a schematic diagram of the balance. K_1 and K_2 are knife edges upon which the scale pans are suspended, and K_3 is the knife edge upon which the whole beam is balanced. Suppose that, with M_1 on the right pan and M_2 on the left pan, the balance comes to rest as indicated in the figure. One must also take into account the effect of the mass of the beam, M_3, in producing equilibrium. When equilibrium is established, the sum of the moments of all the forces acting must be zero.

Hence:

$$(1) \qquad (M_1 + p)\, g\,\ell_1 \sin(\theta_1 - \beta)$$
$$(M_1 + p)\, g\,\ell_2 \sin(\theta_2 + \beta) - M_3\, gr \sin\beta = 0,$$

where $\ell_1 \sin(\theta - \beta)$ is the lever arm of the left pan load, $\ell_2 \sin(\theta_2 + \beta)$ is the lever arm of the right pan load, and $r \sin\beta$ is the lever arm of the center of mass of the beam, if the center of mass is located at a distance r from the knife edge K_3, and p is the mass of either scale pan. By using the relations for the sine of the sum or difference of two angles, equation (2) can be written:

$$(M_1+p)\,\ell_1\,(\sin\theta_1\cos\beta - \cos\theta_1\sin\beta) - M_3 r\sin\beta$$
$$-(M_2+p)\,\ell_2\,(\sin\theta_2\cos\beta + \cos\theta_2\sin\beta) = 0.$$

Because β is kept small in actual practice the above equation holds to a close degree of approximation if

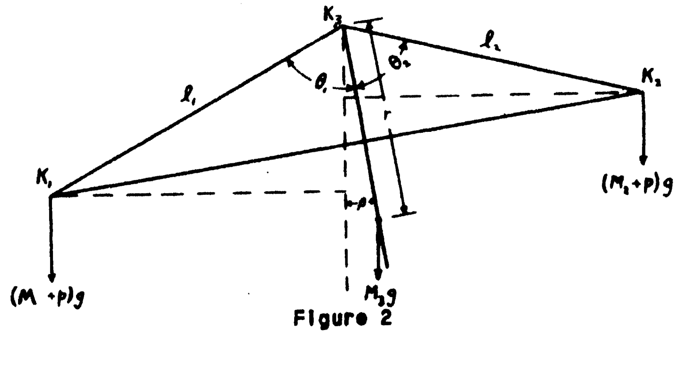

Figure 2

Name: ______ Instructor: ______ Division: ______ Date. ______

Observations, Drawings, Computations: ______

Answers and Conclusions: ______

one substitutes in it:
$\cos\beta = 1$, $\sin\beta = \beta$. Then

$$(M_1+p)\ell_1\ (\sin\theta_1 - \beta\cos\theta_1) - M_3 r\beta - (M_2+p)\ell_2(\sin\theta_2 + \beta\cos\theta_2) = 0.$$

In the usual case $\ell_1 = \ell_2 = \ell$ and

$\theta_1 = \theta_2 = \theta$, and hence:

$$(2)\quad \frac{\beta}{M_1 - M_2} = \frac{\ell\sin\theta}{(M_1+M_2+2p)\ell\cos\theta + M_3 r}.$$

The expression on the left-hand side of the equation is the definition of the sensitivity of the balance (expressed in terms of radians per gram).

With $\ell_1 = \ell_2 = \ell$, $\theta_1 = \theta_2 = \theta$, and $\beta = 0$, $\ell\sin\theta = x$, the perpendicular distance between the line of action of the force $(M_1+p)g$ and the axis of rotation. Also $\ell\cos\theta = h$, the vertical distance between the points of suspension of the pans and the points of suspension of the beam. In terms of x and h, equation (2) becomes:

$$(3)\quad \frac{\beta}{M_1 - M_2} = \frac{x}{(M_1+M_2+2p)h + M_3 r}.$$

An analysis of this expression shows that:

(a) If θ is greater that 90°, i.e. if the knife edges K_1 and K_2 are above the knife edge K_3, then h is negative and the sensitivity of the balance increases with increase of the load.

(b) If $\theta = 90^\circ$, i.e. if all three knife edges are in a straight line, then h is zero and the sensitivity is independent of the load.

(c) If θ is less than 90°, i.e. if the knife edges K_1 and K_2 are below the knife edge K_3, then h is positive and the sensitivity decreases with increase of the load.

(d) In all three cases the sensitivity of the balance increases with increase of the length of the balance arms, and increases with decrease of the distance between the point of suspension of the beam and the center of mass of the beam.

Experiment

Part 1

For the model balance (see Figure 3) measure the length of the arms, weigh each of the scale pans to the nearest gram, and, if the pans are not of equal weight, make them equal by adding the proper weights to the lighter one. Measure the vertical distances between the knife edges holding the scale pans. Weigh the beam of the balance. By sliding a bob along the pointer, the position of the center of mass of the beam may be varied. First place the beam on knife edge K_4 at the groove P and

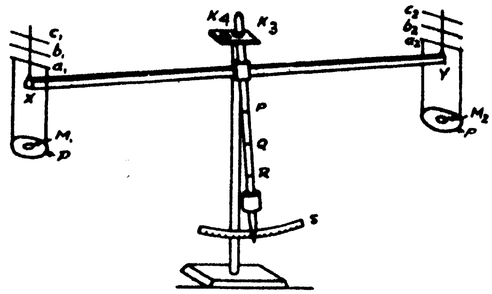

Figure 3

slide the bob along the pointer until perfect balance is obtained. Be careful not to drop the beam in this operation. Then the distance from knife edge K_3 to the groove P gives r_p, the distance the center of mass is from the knife edge K_3. Measure the length of one scale division and also the length of the pointer from the fulcrum to the top of the scale. Record all these measurements in tabular form.

Part 2

With the center of mass fixed at P suspend the pans from the knife edges a_1 and a_2. With no load on the pans find the sensitivity of the balance as follows: Put 10 grams on one scale pan and observe the point of rest. Place the 10 grams on the other pan and observe the new point of rest. Then half the distance divided by the length of the pointer gives the radians deflection for 10 grams. This divided by 10 equals the sensitivity for zero load in radians per gram.

$$\text{Sensitivity} = \frac{\beta}{M_1 - M_2}\ \text{(observed)}. \qquad (4)$$

In the same manner find the sensitivity for a load of 200 grams. Compare these values with those calculated theoretically from equation (3).

Now place the scale pans on b_1 and b_2 and again find the sensitivity of the balance for both zero load and for a load of 200 grams. Repeat the experiment with the scale pans suspended from knife edges c_1 and c_2. Compare the observed and calculated result.

Part 3

Now balance the beam at the groove Q and slide the bob until equilibrium results. This gives the new distance r_q from the center of mass of the beam to the point of suspension. Place the scale pans on the knife edges b_1 and b_2 and find the sensitivity for a load

Name: Instructor: Division: Date.

Observations, Drawings, Computations:

Answers and Conclusions:

of 200 grams in the same manner as in Part 2. Repeat the experiment changing the distance r_q to r_r by a rebalancing of the beam. Compare the observed and calculated results.

A convenient tabulation of the data of the experiment is as follows:

p= ------------------ ℓ =------------

M_3= ------------------h =------------

Length of l scale division= ------------------ r_p =------------

Length of pointer= ------------------ r_q =------------

r_R =------------

$$\text{Calc. Sensitivity} = \frac{x}{(M_1 + M_2 + 2P)\,h + M_3\,r}$$

Position of end knife edges	r	$M_1 + M_2$	$M_1 - M_2$	Point of rest ($M_1 > M_2$)	Point of rest ($M_1 < M_2$)	Sensitivity Obs. Calc.
Below fulcrum						
" "						
Even with fulc.						
" " "						
Above fulcrum						
" "						
Even with fulc.						
" " "						

Name: Instructor: Division: Date.

Observations, Drawings, Computations:

Answers and Conclusions:

TEST EXPERIMENT 6

1. A uniform board a....m. long is balanced on a saw horse. A boy weighing b....kg. sits on one end. Another boy weighing c....kg. balances the first boy by sitting (1) , (2) , (3) , (4) meters from the saw horse.. . . . . ( )

2. An object is balanced by one a....gm. plus two b....gm. masses. If the a....gm. mass is calibrated to within c....% and the b....gm. masses to within d....%, then the weighing is accurate to within (1) , (2) , (3) , (4) . . . . ( )

3. The beam of a balance, including pointer, weighs a....gm. The pointer is b....cm. long. The distance between center and outer knife edges is c....cm. A mass of d....gm. on one pan deflects the pointer so that is moves e....cm. over its scale. The distance of the center of gravity below the plane of the three knife edges is (in cm.) (1) , (2) , (3) , (4) . . . . ( )

4. The sensitivity of a balance is a....scale divisions per mg. When an object is placed in the left-hand pan and two b....gm. masses in the right-hand pan, the pointer comes to rest c....scale divisions to the left of the zero reading. The weight of the object, (in gm.) is (1) , (2) , (3) , (4) . . . ( )

5. Two boys carry an a....lb. basket on a light horizontal pole b....ft. long. If one boy is to exert c....times as much force as the other, each boy grasping the pole by an extremity, the basket should be placed at a distance of (1) , (2) , (3) , (4) , ft. from one end. . . . . ( )

6. An a....lb. ladder b....ft. long lies on the ground. The center of mass of the ladder is c....ft. from one end. The least vertical force necessary to lift one end off the ground is (in lb.) (1) , (2) , (3) , (4) . . . . ( )

7. The least horizontal force applied at the center necessary to roll a wheel a....ft. in radius and weighing b....lb. over an obstacle c....ft. high, assuming the weight of the wheel as acting at its center, is (in lb.) (1) , (2) , (3) , (4) . . ( )

8. An a....inch pointer of a balance is deflected b...inch by a mass of c....gm. placed in one scale pan. The sensitivity of the balance for zero load (in radians per gm.) is (1) , (2) , (3) , (4) . . . . ( )

9. A meter stick is balanced at its a....cm. mark by a force of b....gm. at its c....cm. mark. The weight of the stick (in gm.) is (1) , (2) , (3) , (4) . . . . ( )

10. The beam of a balance whose knife edges are in line with the fulcrum weighs a....gm. The distance between the two knife edges is b....cm. A mass of c....gm. on one pan deflects the pointer through d....cm. of its scale. If the pointer is e....cm. long, the distance along it from the fulcrum to the center of gravity (in cm.) is (1) , (2) , (3) , (4) . . . . ( )

Name: Instructor: Division: Date.

Observations, Drawings, Computations:

Answers and Conclusions:

Experiment 7

STATIC EQUILIBRIUM

Object:

To study the conditions of equilibrium of coplanar forces and to apply them to the derrick.

Apparatus:

The apparatus consists of: Meter stick and inclinometer, a heavy beam AB supported at the top by the rope and spring balance T and at the bottom by spring balances F_1 and F_2. A weight W may be hung at B.

Theory:

When a body is in equilibrium under a system of coplanar forces, the sum of the force components is zero for each of any two directions of resolution and the sum of the moments of the forces about any axis perpendicular to the plane is zero. In the present case it is most suitable to resolve the forces in the horizontal and vertical directions and to take the moments about either A or B.

The center of gravity of a body is defined as the point at which the whole mass of the body can be considered as concentrated. Thus, if we support a body at any point, it will be in equilibrium provided the point of support is directly above or below the center of gravity, i.e,, the lever arm of the weight of the body will be zero, and thus there will be no tendency for the body to rotate.

Experiment

Part I

The apparatus is set up as shown in the sketch. Record all spring balance readings, Measure the length of the beam AB. Measure the angles β and R with an inclinometer. Make a neat diagram to scale and record on it the data obtained.

Note: All lever arms used in the following calculations should be marked with dotted lines on the diagram and their respective lengths recorded as calculated from the values already measured.

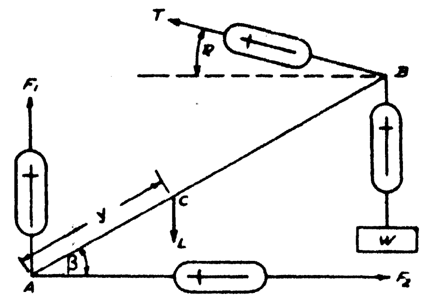

Figure I

In the following calculations the values of the weight of the beam, distance to the center of gravity, and the spring balance reading at T are to be used for purposes of comparison only.

1. From the equations summing up the horizontal components of force, determine the tension in the rope T and compare with the observed value as read from the spring balance at T.
2. Using the calculated value of T and the equation summing up the vertical components of the forces, determine the weight of the beam and compare with the value stamped on it by the Instructor.
3. Using the results of the two previous calculations and the equation of moments with axis at A, determine the distance from A to the center of gravity of the beam and compare it with the position for a uniform beam.

On your data sheet set down in a neat form the calculated and observed values of: (a) the tension in the rope T; (b) the value of the weight of the beam; (c) the distance from A to the center of gravity of the beam.

The force and moment equations with the numerical substitutions for the quantities are to be placed on the data sheet directly beneath the drawing.

Name: ______ Instructor: ______ Division: ______ Date. ______

Observations, Drawings, Computations: ______

Answers and Conclusions: ______

TEST EXPERIMENT 7

1. A uniform plank a....ft. long weighing b....lb. is supported c....ft. from one end. A weight on the short end balances the plank. This weight (in lb.) is (1) , (2) , (3) , (4) . . . . ( )

2. A weight of a....lb. is tied to a point b....ft. from one end of a c....ft. length of rope. The ends of the rope are fastened d....ft. apart to a horizontal beam. The tension in the shorter segment of the rope (in lb.) is (1) , (2) , (3) , (4) . . . . ( )

3. A uniform ladder weighing a....lb. and b....ft. long is leaning against a wall at an angle of c....deg. with the horizontal. The force exerted perpendicularly to the wall (in lb.) is (1) , (2) , (3) , (4) . . . . ( )

4. An a....lb. man is b....the way up the ladder of problem (3). The additional force exerted perpendicularly to the wall (in lb.) is (1) , (2) , (3) , (4) . . . . ( )

5. A uniform rod a....ft. long, weighing b....lb., is hinged to the floor at one end. The other end is supported by a horizontal cord. The rod makes an angle of c....deg. with the floor. The tension in the cord (in lb.) is (1) , (2) , (3) , (4) . . . . ( )

6. A picture weighing a....lb. hangs upon a cord whose parts make an angle of b....deg. with each other. The tension in each part of the cord (in lb.) is (1) , (2) , (3) , (4) . . . . ( )

7. A uniform yardstick weighing a....lb. rests horizontally on two points b....inches and c....inches from one end. The upward reaction on the bar at the point b....inches from the end (in lb.) is (1) , (2) , (3) , (4) . . . . ( )

8. A uniform rod a....ft. long weighing b....lb. is held in a horizontal position by two men. One of them is c....ft. from one end, while the second man is d....ft. from the other end. The upward force exerted by the second man (in lb.) is (1) , (2) , (3) , (4) . . . . ( )

9. A a....ft. rope is tied to two hooks in the ceiling so that when a given mass of b....lb. is tied to its center the angle between the two halves of the rope is c....deg. The tension on each part of the rope (in lb.) is (1) , (2) , (3) , (4) . ( )

10. A triangular frame is made of two uniform beams each a....ft. long, held at an angle of b....deg. to each other by a very light bar between the free ends of the beams. Each beam weighs c....lb. The compression in the bar when the frame is hung from the vertex of the b....deg. angle (in lb.) is (1) , (2) , (3) , (4) . . . . ( )

Name: ______________ Instructor: ______________ Division: __________ Date. ________

Observations, Drawings, Computations: ______________

Answers and Conclusions: ______________

Experiment 8

WORK, MECHANICAL ADVANTAGE AND EFFICIENCY

Object:

To better comprehend the meaning of work, mechanical advantage and efficiency by performing experiments with a simple machine.

Apparatus:

Platform scales, one spring scale (0-100 lbs.), two pulleys, rope and platform.

Theory:

When a force acts upon a body, the product of the force by the distance the body moves in the direction of the force is called the work performed by the force. In the English system the unit of work is the foot-pound, the work done by a force of one pound acting through a distance of one foot. The erg (Metric unit) is the work done by a force of one dyne acting through a distance of one centimeter. A joule is 10^7 ergs. In explanation of the definition of work: The work done by a man pulling a rope is the product of the force exerted times the length of rope passing through his hands.

The actual mechanical advantage of any machine is the ratio of the force developed, to the force applied.

The theoretical mechanical advantage is the ratio of the distance through which the applied force acts to the distance through which the opposing force acts.

By the efficiency of a machine is meant the ratio of the useful work to the energy received.

Experiment

Part 1

A block and tackle is made with the rope and pulleys. With it the platform is suspended from the ceiling, large pulley at the top.

Case (a). The experimenter lifts himself with the platform by pulling on the free end of the rope. The force required for the experimenter to lift himself is measured by the use of scales attached to the free end of the rope. Record this force. Find the weight of the experimenter and the platform by weighing with the platform scales.

Case (b). Repeat the experiment having a second person lift the experimenter by means of the block and tackle.

Case (c). Repeat the experiment by having a second person lift the experimenter, this time with the small pulley at the top.

Draw a diagram for each case. For each case answer the following questions: How does the weight of the experimenter plus platform compare with the force on the free end of the rope? What is the actual mechanical advantage? What is the theoretical mechanical advantage? Can you draw any conclusions as to the tension in each strand of the rope? Can you show any relationship between the number of strands of rope and the theoretical mechanical advantage?

Part 2

In each of the three cases of part 1 calculate the efficiency and also the total work done to raise the experimenter a distance of ten feet. Show that the ratio of the actual mechanical advantage to the theoretical mechanical advantage is equal to the efficiency.

Name: Instructor: Division: Date.

Observations, Drawings, Computations:

Answers and Conclusions:

TEST EXPERIMENT 8

1. The work done winding in up a a....ft. chain which hangs vertically and which weighs b....lb. per ft. (in ft. lb.) is (1) , (2) , (3) , (4) . . . . ( )

2. A windlass with a drum a....in. in diameter has a crank arm b....in. long. If the efficiency is c....%, the force(in lb.) which must be applied to the crank in order to raise a load of d....lb. is (1) , (2) , (3) , (4) . . . . ( )

3. A tapering flag staff weighing a....lb. and b....ft. long, whose center of gravity is at a distance cf c.... of its total length from the thicker end, is raised until the beam makes a d....angle with the horizontal. The work done (in ft. lb.) is (1) , (2) , (3) , (4) . . . . ( )

4. A column a....ft. high was built up of wooden blocks weighing b....lb. per foot of height of column. The work done (in ft. lb.) in setting up this column was (1) , (2) , (3) , (4) . . . . ( )

5. The work (in ft. lb.) necessary to push a barrel weighing a....lb. up a b....ft. frictionless plane inclined at c....deg. to the horizontal is (1) , (2) , (3) , (4) .... ( )

6. To dig a well a....ft. deep, b....lb. of earth of uniform density must be dug out. The work (in ft. lb.) required to do this is (1) , (2) , (3) , (4) . . . . ( )

7. A a....lb. pole whose center of gravity is b....ft. from the base lies on the ground. Using a certain system of ropes and pulleys, it requires c....ft. lb. of work to stand it upright. The efficiency of the operation is (1) , (2) , (3) , (4) . . . . ( )

8. A certain windlass has a drum a....ft. in diameter and a crank arm b....ft. long. A force of c....lb. is required at the handle to raise a mass of d....lb. The theoretical mechanical advantage is (1) , (2) , (3) , (4) . . . . ( )

9. The actual mechanical advantage of the windlass in (8) is (1) , (2) , (3) , (4) . . . . ( )

10. The efficiency of the windlass in (8) is (1) , (2) , (3) , (4) - ( )

Name: ______ Instructor: ______ Division: ______ Date. ______

Observations, Drawings, Computations: ______

Answers and Conclusions: ______

Experiment 9

MOMENTUM AND ENERGY

Object:

To study the principles of the conservation of energy and linear momentum and to measure the speed of a bullet.

Apparatus:

Ballistic pendulum, weights, meter stick, gun.

Theory:

The linear momentum of a body is the product of its mass by the linear velocity. According to the principle of the conservation of energy, it can be stated that when energy is transformed from one kind to another the total energy after the transformation is equal to the total energy before the transformation. Also, according to the principle of the conservation of linear momentum, the total momentum after two bodies collide is equal to the total momentum before the collision.

In Figure I two bodies are assumed to approach each other with their relative velocity of approach equal to $V_0 - v_0$ and to collide, after which their relative velocity of separation is $(V - v)$.

It has been found that the relative velocity of separation is always proportional to the relative velocity of approach and that the proportional factor e is a measure of the elastic property of the bodies; it is called the elastic constant or coefficient of restitution.

If put in mathematical form the above-stated principles appear as follows:

Conservation of Energy:

$$\frac{1}{2} m_1 V_0^2 + \frac{1}{2} m_2 v_0^2 = \frac{1}{2} m_1 V^2 + \frac{1}{2} m_2 v^2 + \text{loss.} \qquad (1)$$

Conservation of Momentum:

$$m_1 V_0 + m_2 v_0 = m_1 V + m_2 v \quad . \qquad (2)$$

Velocities of approach and separation are proportional:

$$e(V_0 - v_0) = -(V - v). \qquad (3)$$

From these three equations the loss of energy during the impact can be calculated in terms of the elastic constant and the masses.

If the bodies remain together after impact so that their relative velocity is zero, then e is zero in value and the impact is inelastic. This case only will be considered in this experiment and equation (2) becomes:

$$m_1 V_0 + m_2 v_0 = (m_1 + m_2) V. \qquad (2a)$$

Experiment A

Part 1

Figure 2 shows twin ballistic pendulums with cords of length ℓ and blocks of wood each of mass m_1 attached to the cords at their bottom ends.

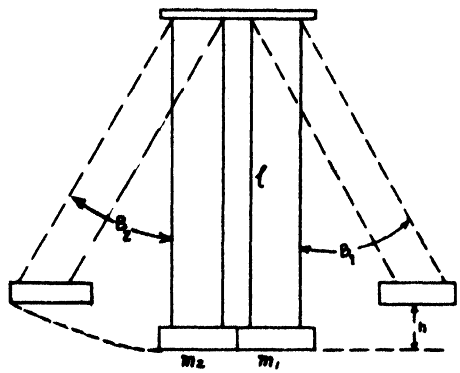

Figure 2

If one mass is swung out so that its cord makes an angle B_1 with the vertical and then released, the velocity of approach V_0 just as it collides with the other one can be calculated from the angle B_1 of the cord and its length ℓ, together with the principle of the conservation of energy.

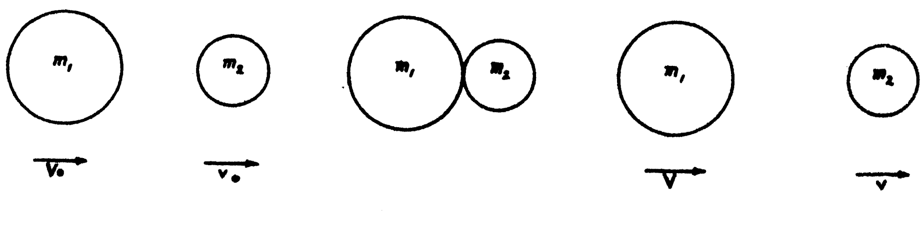

Figure I

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Observations, Drawings, Computations:

Answers and Conclusions:

This is done as follows:

$$m_1 g h_1 = m_1 g \ell (1 - \cos B_1) = \frac{1}{2} m_1 V_o^2$$

$$v_o = 0 \quad ,$$

$$V_o = \sqrt{2 g \ell (1 - \cos B_1)} \quad .$$

After impact the two masses go on together and have the same velocity V which can be found from the angle B_2 which the cord makes with the vertical after impact at its greatest swing.

Then $V = v = \sqrt{2 g \ell (1 - \cos B_2)}$. (5)

Assuming that no outside forces are acting, such as air resistance, equation (2a) holds for these measured values.

Perform the above experiment 5 times and substitute in equation (2a).

Make m_2 double m_1 and repeat the experiment 5 times--what are the errors?

Part 2:

A small rifle is held in place horizontally so that its bullet will hit the mass m_2 and become embedded in it.

The angle B_2 is noted as the pendulum swings out after impact.

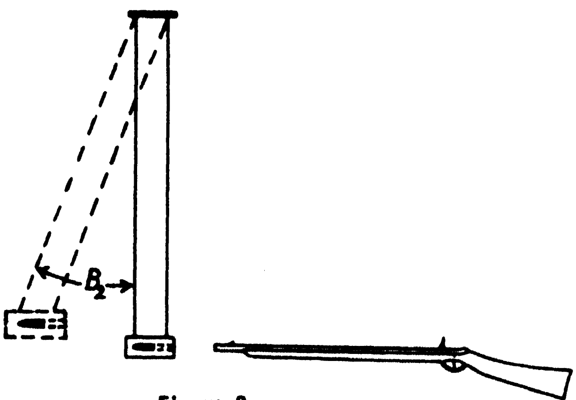

Figure 3

Equation (2a) can be used to calculate the speed of the bullet, which weighs 1.75 gms.

Perform this experiment at least twice and find the speed of the bullet in feet per second.

Part 3

Calculate the percentages of kinetic energy lost during impacts in Parts 1 and 2.

Experiment B

The pendulum consists of a massive cylindrical bob suspended by a strong light rod supported at its upper end by pivot bearings (see Fig. 4). The pendulum support is a rigid bracket mounted upon the end of a steel rod fastened in the base. The pendulum bob is hollowed out to receive the projectile, a brass sphere. The projecting apparatus is a spring-actuated gun mounted at one end of the base. The brass ball is drilled for mounting on the end of the propelling rod. When the sphere is fired into the bob, the pendulum swings upward and is caught at its highest point by a pawl which engages a tooth in the curve rack. A scale along the outer edge of the rack enables one to record the position of the pendulum.

Part 1:

Since the ball is caught and held within the pendulum, an inelastic collision occurs. Let m_1 represent the mass of the pendulum and m_2 that of the sphere; let v_o represent the initial velocity of the ball, and V the final velocity of ball and pendulum. Then

$$m_2 v_o = (m_1 + m_2) V. \qquad (6)$$

From the principle of conservation of energy it follows that the kinetic energy of the pendulum immediately after impact is equal to its potential energy at the highest point in its path. This may be written:

$$(m_1 + m_2) \frac{V^2}{2} = (m_1 + m_2) gh,$$

where h is the vertical rise of the center of gravity of the pendulum. Hence

$$V = \sqrt{2 gh}. \qquad (7)$$

Determine m_2 and m_1 by weighing the sphere and by removing the pendulum from its support and weighing it. Fire the ball into the pendulum five times, and each time measure h (note that the position of the center of gravity is marked on the pendulum bob). For each h, calculate the corresponding V from equation (7) and the corresponding v_o from equation (6), Find the average initial velocity of the ball.

Part 2:

The initial velocity of the ball, v_o , may be found by an application of the laws of motion. Remove the pendulum and place the apparatus in such

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Observations, Drawings, Computations:

Answers and Conclusions:

a position that the ball will travel in a path not touching any other obstacle before striking the floor. Fire the ball five times, each time marking with chalk or with carbon paper the point at which it strikes the floor. Each time measure s, the horizontal distance traveled by the ball, and y, the vertical fall of the ball. Find the average values of x and y. The laws of motion give (since v_o is a horizontal initial velocity):

$$x = v_o t$$

$$y = 1/2\ g\ t^2 .$$

Elimination of the time gives:

$$v_o^2 = 1/2\ g\ \frac{x^2}{y} . \tag{8}$$

Use the average measured values of x and y to calculate the initial velocity of the ball, v_o, from equation (8). How does this value compare with the average of that found in Part 1? Calculate the percentage error.

__Part 3:__

Calculate the percentages of kinetic energy lost during the impacts of Part 1.

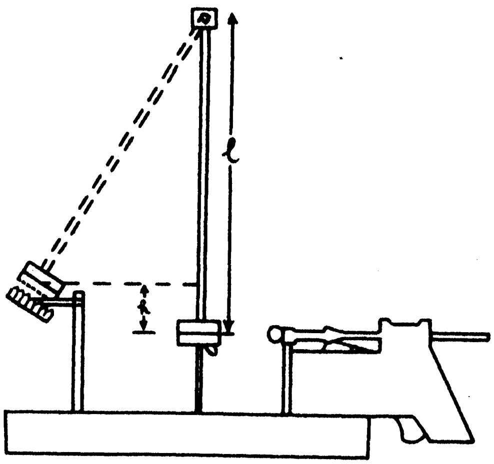

Figure 4

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Observations, Drawings, Computations:

Answers and Conclusions:

TEST EXPERIMENT 9

1. An a....gm. gun fires a b....gm. bullet with a velocity of c....cm./sec. The initial velocity of recoil of the gun (in cm. /sec.) is (1) , (2) , (3) , (4) . . . . ( )

2. An a....gm. ball having a velocity of b....cm./sec. strikes a c....gm. stationary cylinder that is free to move. After the inelastic impact, their velocity (in cm./sec.) is (1) , (2) , (3) , (4) . . . . ( )

3. The fraction of the kinetic energy transformed into heat in the above problem is (1) , (2) , (3) , (4) . . ( )

4. Two inelastic bodies (one of mass a....lb. moving with velocity b....ft./sec.; the other of mass c....lb. moving with velocity d....ft./sec) collide. The velocity of the masses after collision is (in ft./sec.) (1) , (2) , (3) , (4) . . . . ( )

5. A car weighing a....tons moving b....ft.sec. collides and couples with a car weighing c....tons moving in the opposite direction with a velocity of d....ft./sec. Find the velocity (in ft. /sec.) after impact. (1) , (2) , (3) , (4) . . . ( )

6. Two inelastic bodies of masses a....and b....gm. collide when traveling in the same direction with velocities of c....and d.... cm./sec. respectively. The velocity (in cm./sec.) after impact is (1) , (2) , (3) , (4) . . . . ( )

7. If the bodies in problem (6) were perfectly elastic, the velocity of the lighter ball after impact would be (in cm./sec.) (1) , (2) , (3) , (4) . . . . ( )

8. Two railroad cars are coasting in the same direction. m_1 is a....lb.; m_2 is b....lb.; v_1 is c....ft./sec.; v_2 is d....ft. /sec. Car number 2 catches up with car number 1 and couples on to it. Their velocity (in ft./sec.) is (1) , (2) , (3) , (4) . . . . ( )

9. Two perfectly elastic ivory balls of the same masses approach each other with speeds of a....cm./sec. in their respective directions and collide. The relative velocity with which the two separate (in cm./sec.) is (1) , (2) , (3) , (4) . . . . ( )

10. A a....gm. bullet in passing through a ballistic pendulum has its speed changed from b....to c....cm./sec. The momentum imparted to the pendulum (which was initially at rest) was (in gm. cm./sec.) (1) , (2) , (3) , (4) . . . . ( )

Name: Instructor: Division: Date.

Observations, Drawings, Computations:

Answers and Conclusions:

Experiment 10

SIMPLE HARMONIC MOTION

Object:

To find the period of vibration of a mass on the end of a spiral spring and to investigate the effects of change of amplitude of motion, mass, and force constant of the spring upon the period.

Apparatus:

Large coiled brass springs, weight holder and set of weights, stand for supporting spring, meter stick, and stop watch.

Theory:

The projection upon a diameter of a point moving in a circle with constant speed moves with

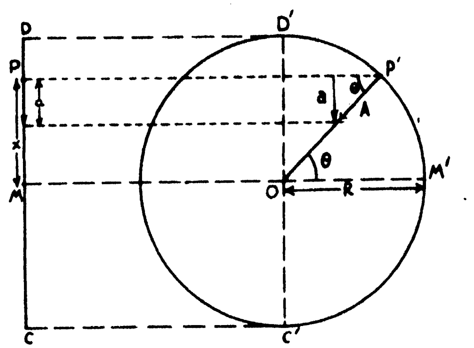

Figure 1

varying speed and describes a complete vibration on the diameter while the point moves completely around the circumference. See Figure 1. P' represents the point moving in a circular path with constant speed V, and P is the projection of P' upon a diameter. The motion of P is called simple harmonic motion.

R represents the radius of the circle of reference, and θ the angle between OP' and OM'. PM = x, the displacement of P from M, its position of equilibrium. Then

(1) $$x = R \sin \theta.$$

In uniform circular motion, there is at every instant an acceleration toward the center. The acceleration of P' toward the center O is:

$$A = \frac{V^2}{R}.$$

The acceleration a of P toward M is the component along OD of A.

(2) $$a = \frac{-V^2}{R} \sin \theta.$$

The minus sign indicates that the acceleration is downward when the displacement is upward, and vice versa. Dividing (2) by (1), one obtains

(3) $$\frac{a}{x} = -\frac{V^2}{R^2}, \text{ or}$$

$$a = \frac{-V^2}{R^2} x.$$

Since neitner V nor R changes numerically during the motion, V^2/R^2 is a constant; and since V and R are both real quantities, V^2/R^2 is always positive. This means that for every position of P the ratio of the acceleration of P to its displacement is a constant and that the acceleration and the displacement are always opposite in direction.

According to Newton's Second Law of Motion, the force F necessary to give an acceleration a to a body of mass m is:

$$F = m a.$$

If a body of mass m moves with simple harmonic motion, its acceleration a is given by equation (3), so that

$$F = m a = -m \frac{V^2}{R^2} x.$$

Represent the constant mV^2/R^2 by c'. Then

(4) $$F = -c'x.$$

The above equation symbolically expresses Hooke's Law, namely that "stress (force) equals a constant times strain (stretch)."

The period of a simple harmonic motion is defined as the time necessary for the particle P to make one complete vibration from one end of its path to the other end and back again. The period is also equal to the time necessary for the point P' to move once around the circle of radius R. In the period T the point P' moves at a constant speed V through a distance 2 π R. Hence

$$2 \pi R = V T, \text{ or}$$

$$T = \frac{2 \pi R}{V}.$$

From equation (3),

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Observations, Drawings, Computations:

Answers and Conclusions:

$$V^2 = \frac{-R^2 a}{x}, \quad \text{and}$$

$$V = R\sqrt{\frac{-a}{x}} .$$

So the period T is given by:

(5) $$T = 2\pi\sqrt{\frac{-x}{a}}$$

Application of Theory:

If a body of mass m is hung at the end of a light spring and the mass is set into vertical motion, this motion is a very good approximation to simple harmonic motion. This is because the restoring force exerted by the spring upon the mass is proportional to the elongation of the spring (or displacement of the mass) and in the opposite direction. But this is simply a restatement of equation (4), that the force acting upon a body moving with simple harmonic motion is equal to a negative constant times the displacement of the body from its position of equilibrium. Since the motion of the body is simple harmonic, the period of the motion is given by equation (5). Equation (4) may be written:

$$F = -c'x = m\,a.$$

Then

(6) $$\frac{-x}{a} = \frac{m}{c'} .$$

Equation (6) may be substituted into (5) to obtain:

(7) $$T = 2\pi\sqrt{\frac{m}{c'}} .$$

Since the spring as well as the mass on the end is set into motion, the mass of the spring M_s must be considered if M_s is not very small as compared to the mass m on the end of the spring. If M_s is not sufficiently small to be neglected, the effective mass accelerated is $m + M_s/3$ where $M_s/3$ is the "effective" mass of the spring. Therefore, for heavy springs, the period is given by:

(8) $$T = 2\pi\sqrt{\frac{m + M_s/3}{c'}}$$

Experiment

Part I

Determination of Force Constant. Place the long spring and weight holder on the stand and adjust the pointer near the scale so that it can be read without error of parallax. Read the zero position to the nearest tenth of a millimeter. Load the pan with a 100 gm. mass and read the position. Continue adding 100 gm. masses until a load of 500 gm. is on the pan.

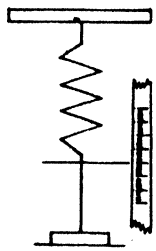

Figure 2

Unload the masses one by one, taking the reading of each position. Average these readings with those previously taken. Plot a graph of load against deflection. The slope of the best line drawn through the points gives the force constant c' in gm./cm. Calculate from this the value of c' in dynes/cm.

Hang 500 gm. on the spring by means of a cord about 50 cm. long. Pull the 500 gm. mass down about 2 cm. and release. Notice the transfer of potential to kinetic energy and vice versa as the system oscillates. To time the oscillations, release the 500 gm. mass so that it is at the center of its path when the stop watch is started. (In counting be sure to start with zero.) Count 100 oscillations. Repeat this series of observations with a different number of oscillations.

In order to test the dependence of period upon the amplitude, repeat the above observations for oscillations with an initial amplitude of 10 cm.

Part 2.

Weigh the spring to determine M_s. Calculate the period T from equation (8). Check this value with the value of T experimentally measured in Part I.

To test dependence of period upon mass, increase m to 500 gm. and take two series of observations of the period. Calculate the period from (8) and compare with the experimental value.

Part 3.

Discuss the errors of observation and point out where precautions are most necessary.

Cite three <u>different</u> kinds of systems in which there is the interchange of potential and kinetic energy in such a way as to give simple harmonic motion.

Name: ______________ Instructor: ______________ Division: ________ Date. ________

Observations, Drawings, Computations: ______________

Answers and Conclusions: ______________

TEST EXPERIMENT 10

1. A body vibrates along a straight line with S.H.M. If the period T is a....sec., the acceleration of the body when it is b....cm. from the midpoint of its path is (in cm./sec.^{2}) (1) , (2) , (3) , (4) . . . . ( )

2. A spring is stretched a....cm. by a force of b....dynes. By a force of c....dynes, it will be stretched (1) , (2) , (3) , (4) cm. . . . . ( )

3. The constant of the spring in problem (2) (in dynes per cm. of stretch) is (1) , (2) , (3) , (4) . . . . . ( )

4. A light spring with a....gm. on the end has a period of b.... sec. The force per unit stretch (in dynes) is (1) , (2) , (3) , (4) . . . . ( )

5. A light spring with a....lb. on the end has a period of b....sec. The force (in lb.) for a 1 ft. stretch is (1) , (2) , (3) , (4) . . . . ( )

6. A spiral spring weighs a....gm. and has a mass of b....gm. on its free end. The force constant of the spring is c....dynes/ cm. Its period of vibration (in sec.) is (1) , (2) , (3) , (4) . . . . ( )

7. Two springs have the same force constant. One is extremely light and when a load of a....gm. is attached to the end has a period T_1. The other weighs b....gm. and when a....gm. is attached to its free end, it has a period T_2. The ratio T_1/T_2 is (1) , (2) , (3) , (4) . . . . ( )

8. A period of a....sec. results when a b....gm. spring whose force constant is c....dynes/cm. is loaded with a mass (in gm.) of (1) , (2) , (3) , (4) . . . . ( )

9. A weight of a....gm. is vibrating in S.H.M. making 1 complete vibration in b....sec. The force acting on it when it is c....cm. from the center of its path is (in dynes) (1) , (2) , (3) , (4) . . . . ( )

10. A mass in S.H.M. has a maximum displacement of a....cm. and makes one complete vibration in b....sec. Its maximum velocity (in cm./sec.) is (1) , (2) , (3) , (4) . . . ( )

Name: Instructor: Division: Date.

Observations, Drawings, Computations:

Answers and Conclusions:

Experiment II

DETERMINATION OF YOUNG'S MODULUS OF ELASTICITY BY HOOKE'S LAW

Object:

To find Young's Modulus for a steel wire.

Apparatus:

Young's Modulus apparatus, micrometer caliper, set of weights, 10 ft. scale.

Theory:

When a force of any kind acts on a body the body will be deformed to some extent. A substance is considered to be elastic if this deformation disappears when the force is removed, and inelastic if the body does not return to its original shape.

Hooke, who made quantitative investigations of the elasticity of materials, found that the deformation of a body was directly proportional to the force applied and inversely proportional to the area over which the force is spread. The force exerted per unit area is defined as "stress." He also found that for a given stress the deformation depended upon the size of the body. In the case of wires, it was found that the elongation was proportional to the length of the wire. The elongation per unit length is called the "strain." Hooke's results may therefore be summed up in the law that the stress is proportional to the strain.

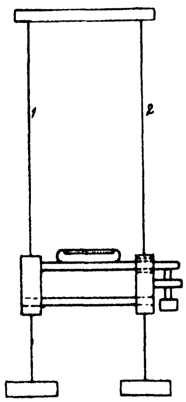

Figure I

For a wire or rod the ratio of the stress, expressed as force per unit area, to the strain expressed as elongation per unit length, is called Young's Modulus of Elasticity.

Hooke's Law is true for a perfectly elastic substance, but most substances do not remain elastic under excessive stress. Thus, India rubber does not follow Hooke's law exactly even under moderate stresses.

Experiment

Part I

The apparatus consists of two identical steel wires hung from a single bracket and attached at their lower ends to a flexible framework. One of the wires carries a small weight to keep it taut, while the other is attached to a micrometer screw and a pan to carry several weights. A spirit level is attached to the first wire and rests on the micrometer screw of the second wire. Adjust the screw until the spirit level is horizontal, and take the reading on the screw as the zero reading. Add a 500 gm. mass to the pan of the second wire and readjust the micrometer screw until the level is again horizontal and note the reading. Repeat by adding 500 gm. each time and taking a reading each time until a total of 4.5 kgms. have been placed on the pan.

Now remove 500 gm. masses each time and take a reading at each unloading until finally the pan is empty. (The final reading should not differ from the initial reading by more than .2 mm. If it does, then repeat the experiment, taking more time and care to make your readings.) Take the mean of the observations for each load as the actual reading for that load. Tabulate your data. Now subtract the first reading from the third, the second from the fourth, etc., and obtain four values for the increase in length when the load is increased by 1.0 kg. Take the average of these as the best value.

Measure the diameter of the wire with a micrometer gauge at 5 different places along the wire, taking two readings at right angles to each other at each place. This must be done very carefully. The length of the wire is given by the Instructor.

Calculate the stress in dynes/cm.^{2} and also the strain. From these calculate Young's Modulus for steel and give the units.

Convert your result into the F.P.S. (British) system.

Part 2

Would a change of temperature or a vertical motion of the support affect the results in Part I?

Show that the method of averaging used in Part I is a better representation of the accuracy of your measurements than if you would only average the difference for each 500 gm. increase in load.

Calculate the potential energy of the wire when loaded with 4.5 kg.

Name: ____________ Instructor: ____________ Division: ________ Date. ________

Observations, Drawings, Computations:

Answers and Conclusions:

TEST EXPERIMENT II

1. Two light wires of the same length and diameter are joined together end to end. This arrangement is suspended vertically with a weight hanging on the lower end. The Young's modulus for the upper wire is a....dynes/sq.cm. and b....dynes/sq.cm. for the lower wire. The weight elongates the upper wire c....cm. The elongation (in cm.) of the lower wire is (1) , (2) , (3) , (4) . . . . ( )

2. Young's modulus for steel is a....dynes/sq.cm. The force (in dynes) required to give a steel wire of length b....cm. and cross-sectional area c....sq.cm. an elongation of d....cm. is (1) , (2) , (3) , (4) . . . . ( )

3. If a wire would break at a....lb. per sq.ft., the length in feet of the same kind of wire with a cross-sectional area of b....sq.ft. and a density of c....lb./cu. ft. that would hang freely without breaking is (1) , (2) , (3) , (4) . ( )

4. A a.... meter length of wire whose cross-sectional area is b....sq.cm. and whose breaking point is c....kg. per sq. cm. is used to hang a picture. If both ends are fastened to the picture and the wire is strung over a hook so that its two equal sections make an angle of d....deg. with each other, the heaviest picture that can be hung weighs (in kg.) (1) , (2) , (3) , (4) . . . . ( )

5. A wire a....meters long whose cross-section is b....sq.cm. is stretched c....cm. by a weight of d....kg. Young's modulus is (in dynes per sq. cm.) (1) , (2) , (3) , (4) . . . ( )

6. The Young's modulus of a wire a....ft. long whose cross-sectional area is b....sq. in. is c....lb./sq.in. A force of d.... lbs. will stretch it a distance (in ft.) of (1) , (2) , (3) , (4) . . . . ( )

7. A wire a....meters long and b....sq.mm. in cross-sectional area is stretched c....cm. Its Young's modulus is d....dynes/sq. cm. The potential energy in the stretched wire is (in ergs) (1) , (2) , (3) , (4) . . . . ( )

8. A wire is stretched a....cm. by a force of b....kg. The potential energy in the stretched wire is (in ergs) (1) , (2) , (3) , (4) . . . . ( )

9. A wire a....cm. in diameter is wrongly read as b....cm. in diameter. This introduces an error in the calculation of Young's modulus of (1) , (2) , (3) , (4) . . . . ( )

10. An elevator must carry a load of a....lb. with an acceleration of b....ft./sec.^{2}. If the safe working stress of a steel cable is c....lb. per sq.in., the minimum cross section (in sq. in.) of the cable used is (1) , (2) , (3) , (4) . . . . ( )

Name: ______________________ Instructor: ________________ Division: ______ Date. ______

Observations, Drawings, Computations: ____

Answers and Conclusions: ____

Experiment 12

ARCHIMEDES' PRINCIPLE

Object:

To make use of Archimedes' Principle to calibrate an hydrometer and to determine the density and specific gravity of a solid and liquid.

Apparatus:

Hydrometer, 100°C. thermometer, Vernier caliper, meter stick, ice, graduate, samples, scales and weight.

Theory:

The mass per unit volume is called the density of a body. Letting m represent the mass of a body, V the volume, and d the density of the body:

$$(1) \qquad d = \frac{m}{V} .$$

The specific gravity of a liquid is defined as the ratio of the density of a liquid to the density of water at 4 degrees C. In other words, it is the number of times heavier the given liquid is than the same volume of water at 4°C. The hydrometer is an instrument used to find the specific gravity of a liquid. A sketch of the instrument is shown in Figure 1.

According to Archimedes' Principle, the weight of the liquid displaced equals the weight of the instrument when floating in the liquid. This can be stated in letters as follows:

$$V_o\, d\, g = m\, g,$$

where V_o is the volume of the displaced water (for the K level) at 4°C. and m is the total mass of the hydrometer. Since d is 1 gm./cc., numerically

$$V_o = m \text{ for water at } 4^oC.$$

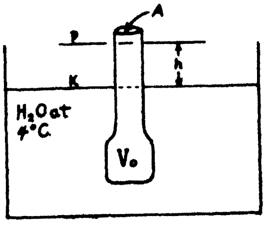

Figure 1.

If the instrument be placed in a liquid of density, d_1 such that it floats with the surface at P, Archimedes' Principle gives:

$$V_o\, d_1\, g + A\, h\, d_1\, g = mg,$$

where A represents the cross-sectional area of the stem of the hydrometer and h the distance between the P and K levels. Then

$$(2) \quad \text{sp.g.} = \frac{d_1}{d_w} = \frac{m}{(V_o + Ah)\, d_w} = \frac{m}{m + A\,h}$$

If m, A, and h are measured, V_o and the Sp.g. can be found experimentally.

From the relation W = m g, the masses of bodies are proportional to their weights at any single place (g = constant). If we weigh a body using an equal-arms balance, we are comparing its mass and its weight with the mass and weight of the standards used. It is customary to say that a standard mass of one pound has a weight of one pound, a standard mass of one gram has a weight of one gram. Since we determine the mass of a body by comparing its weight with that of the standard masses, the usual units for density are pounds/cu. ft. and grams/cc.

Archimedes' Principle states that the buoyant force acting upon a body submerged in a liquid is equal to the weight of the liquid displaced. In determining the density of a solid, this principle is useful in finding the volume of a given body.

Supposing that the body weighs m_a grams in air, its mass is m_a grams. Suppose also that it has an apparent weight m_w grams in water. From Archimedes' Principle the volume is:

$$(3) \qquad V = \frac{m_a - m_w}{d_w} ,$$

where d_w is the density of water. From this:

$$(4) \qquad d = \frac{m_a}{V} = \frac{m_a d_w}{m_a - m_w} .$$

Suppose now that the body has an apparent weight of m_1 grams in a liquid of unknown density. From Archimedes' Principle, the weight of the volume V of the liquid is $m_a - m_1$, where V is given by equation (3). Then use equation (1) to obtain:

$$(5) \qquad d_1 = \frac{(m_a - m_1) \quad d_w}{m_a - m_w} .$$

Experiment

Part 1.

Weigh the hydrometer carefully and measure the diameter of the stem with a vernier caliper. Put the hydrometer into ice water at 4°C. to get the reading at K, the surface of the water. Measure a series of distances h, one for each main reading on the hydrometer. Calculate the sp.g. for each value of h, and plot a curve with the hydrometer readings as abscissae and the differences between these readings and the calculated values as ordinates. Such a curve can be used as a correction curve for the hydrometer.

Name: ______________ Instructor: ______________ Division: ________ Date. ________

Observations, Drawings, Computations: ______________

Answers and Conclusions: ______________

Part 2

Measure a series of distances h for the Baume' scale with equal divisions of length, and calculate the sp.g. corresponding to each mark on the scale.

Part 3

The Baume' scale for liquids lighter than water starts at zero for a 10% solution of salt water. It reads 10° for water at $4^{\circ}C.$ and 70° for liquids of sp.g. .700. Let q be the distance from K to P, where P is the surface of liquids of sp.g. .700.

If q be divided into 60 parts, each part will be the length of each Baume' degree, and for any reading b on the Baume' scale, the corresponding distance h is $\frac{q}{60}(b - 10)$. From Equation 2 one gets:

$$(6) \quad \text{sp.g.} = \frac{m}{m + \frac{Aq}{60}(b-10)} = \frac{1}{1 + \frac{Aq}{60m}(b-10)}$$

Calculate the value of Aq/60m for your hydrometer and check your Baume' scale calibration with equation (6).

Part 4

Using the equal-arms balance, weigh the sample (solid) in air, and find the apparent weights in water and in the solution given. Take the temperatures of the water and of the solution. Look up in a table the density of the water d_w. Using equations (4) and (5), calculate the densities of the body and of the solution.

The specific gravity of any substance is defined as the ratio of the density of the substance to the density of water at $4^{\circ}C.$ d_w at $4^{\circ}C.$ is 1gm./cc. or 62.4 lb./cu.ft. Calculate the specific gravities of the solid and the liquid used. From these values calculate the densities in the British engineering system of units.

Name: Instructor: Division: Date.

Observations, Drawings, Computations:

Answers and Conclusions:

TEST EXPERIMENT 12

1. An a....gm. hollow sphere just floats when completely submerged in water. If the shell is of aluminum (sp.gr.2.6), the volume of the cavity (in cc.) is (1) , (2) , (3) , (4) . . . ( )

2. A light balloon is first filled with hydrogen (density approx. 0.09 gm./liter) and then with helium (density approx. 0.18 gm./liter). Neglecting the wt. of the balloon and taking the volume upon inflation as a....cc., the lifting force of this balloon when filled with hydrogen is b....gm. When filled with helium, the lifting force of the balloon is (in gm.) (1) , (2) , (3) , (4) . . . . ( )

3. The density of a block of wood is a....gm./cc. The fraction of its volume which will remain above the surface when it is floating in water is (1) , (2) , (3) , (4) . . . . ( )

4. If the specific gravity of a liquid is a...., the amount of water to be added to b....gm. of the liquid to get a mixture of sp.gr. c....is (in gm.) (1) , (2) , (3) , (4) . . . ( )

5. The specific gravity of a metal is a.... The weight of b.... cu. ft. of such a metal is (in lb.) (1) , (2) , (3) , (4) . . . . ( )

6. The apparent weight of a....cu. ft. of a metal of sp. gr. b....when immersed in water is (in lb.) (1) , (2) , (3) , (4) . . . . ( )

7. A block of metal weighs a....lb. in air and b....lb. in water. Its sp. gr. is (1) , (2) , (3) , (4) . . . . . . ( )

8. A stone of sp. gr. a....weighs b....lb. in air and c....lb. in oil. The sp. gr. of the oil is (1) , (2) , (3) , (4) . . . . ( )

9. A tube of glass a....cm. in length and b....sq. cm. in cross-section is sealed at both ends after some mercury is placed in it. When floating upright in water, the surface of the water is c.... cm. from the bottom end. When the tube is placed in alcohol of sp. gr. 0.8, the surface of the alcohol will be at a distance from the bottom of the tube equal (in cm.) to (1) , (2) , (3) , (4) . . . . ( )

10. If the tube of problem 9 is floated in a salt solution, the surface of the solution is a....cm. from the bottom of the tube. The sp. gr. of the solution is (1) , (2) , (3) , (4) . . . . ( )

Name: Instructor: Division: Date.

Observations, Drawings, Computations:

Answers and Conclusions:

Experiment 13

COEFFICIENT OF EXPANSION OF A LIQUID

Object:

To determine the absolute coefficient of cubic expansion of oil.

Apparatus:

Regnault's Apparatus as provided in the laboratory, meter stick.

Theory:

Since the volume of any container changes with temperature, it is impossible to determine the true expansion of a liquid by direct measurement in a simple vessel. Such a measurement would give what is known as the apparent or relative expansion, which is the difference between the two expansions, that of the liquid and that of the vessel.

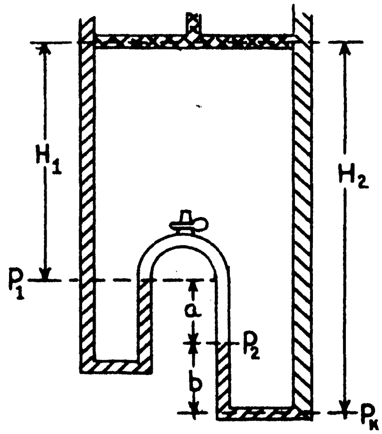

Figure 1

The French physicist, Regnault, devised a method whereby the actual expansion and the coefficient of expansion could be determined from direct measurements without having to take into account any changes in volume of the container. This method employs the principle of balancing liquid columns and the fact that the density of a given mass of material varies inversely with its volume. The arrangement of the apparatus is shown in Figure 1.

Vertical tubes about one meter in length are connected by a horizontal tube near the upper ends and by an inverted U-tube at the lower ends. The system is filled with the liquid (oil) whose coefficient of expansion is to be determined, so that the liquid will flow through the horizontal tube, keeping the upper surfaces in the vertical tubes at the same level. Sufficient air is left in the inverted U-tube to keep the short columns separated. The liquid in the left-hand tube is kept cool at a temperature t_1 and the liquid in the right-hand tube, over a length H_2, is heated to a temperature t_2 by means of a steam jacket. Then the oil in H_2 becomes less dense and is no longer able to balance the other columns. Hence the oil rises in the left-hand branch of the U-tube and falls in the right hand branch.

Consider the pressures at the various levels denoted by P_c, K_k, P_1 and P_2. The pressure P_k at the bottom of the heated column is:

$$P_k = P_c + H_2 d_2 g, \qquad (1)$$

where P_c is the pressure at the top of the heated tube and d_2 is the density of the heated liquid. From the figure it is seen that:

$$b = H_2 - H_1 - a.$$

The pressure P_2 may be expressed as:

$$P_2 = P_k - bd_1 g,$$

where d_1 is the density of the cool liquid. By using eq. (1) and the expression for b, P_2 is put into the form:

$$P_2 = P_c + H_2 d_2 g - (h_2 - H_1 - a) d_1 g. \qquad (2)$$

The pressure P_1 is:

$$P_1 = P_c + H_1 d_1 g. \qquad (3)$$

But since the columns of the U-tube are balanced, $P_1 = P_2$ and hence eq. (2) and (3) are set equal:

$$P_c + H_2 d_2 g - H_2 d_1 g + H_1 d_1 g + ad_1 g = P_c + H_1 d_1 g$$

$$H_2 d_2 g - H_2 d_1 g + ad_1 g = 0$$

$$\frac{d_1}{d_2} = \frac{H_2}{H_2 - a} . \qquad (4)$$

Denoting the coefficient of expansion of the liquid by β, the volume becomes:

$$V_t = V_o (1 + \beta t).$$

But

$$V_o = \frac{m}{d_o} \text{ and } V_t = \frac{m}{d_t} .$$

Hence

$$\frac{1}{d_1} = \frac{1}{d_o} (1 + \beta t_1) ,$$

and

$$\frac{1}{d_2} = \frac{1}{d_o} (1 + \beta t_2) .$$

Name: ______________________ Instructor: ______________________ Division: __________ Date. __________

Observations, Drawings, Computations: ______________________

Answers and Conclusions: ______________________

Elimination of d_0, the density of the oil at 0^oC, gives:

$$\frac{d_1}{d_2} = \frac{1 + \beta t_2}{1 + \beta t_1} \quad . \qquad (5)$$

Substituting eq. (4) and solving for β gives:

$$\beta = \frac{a}{H_2\,(t_2 - t_1) - at_2} \, . \qquad (6)$$

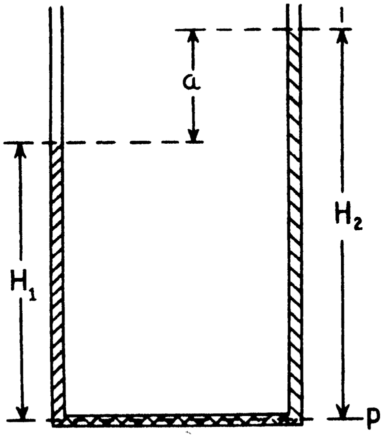

Figure 2

Another arrangement which embodies the same principles is shown in Figure 2. By the same line of reasoning one can prove that (6) holds for this arrangement as follows:

As before, $\frac{d_1}{d_2} = \frac{1 + \beta t_2}{1 + \beta t_1}$ and $H_1 = H_2 - a$.

At P $\quad H_2 d_2 g = H_1 d_1 g$.

By eliminating d_1, d_2, and H_1 and solving for β one gets equation (6).

Experiment

Part 1

The instructor will see that the oil levels in the tubes are properly adjusted. Open the water valve about one fourth turn, or just enough to let water flow slowly through the cooling jacket. Too rapid water flow may burst some of the hose connections.

See that there is plenty of water in the boiler. If it boils noisily, fresh water or some bits of glass in the boiler may be necessary. After steam begins to flow from the heater jacket, note the value of "a" at intervals of a few minutes until no further definite change is observable. The oil may now be assumed to be at steam temperature, which latter may be determined from the barometer reading.

Measure "a" by means of the vertical scales and H_2 with a meter stick. Index points are provided to assist in measuring H_2. Each student in the group is to make these measurements independently, after which the results should be compared. If they check quite well, use them for computing. If they do not check, repeat the readings and find out if possible why they did not check. A student working alone should make two or three separate readings.

Part 2

Is it apparent to you that this method will give the absolute coefficient of expansion of a liquid? In what manner will the following affect the results? (Give reasons for your answers.) (a) Nonuniformity of the inside diameter of the tubes used in the apparatus; (b) Differences of temperature of the liquid in the two arms of the U-tube; (c) Inclination of the oil tubes.

Name: ______________ Instructor: ______________ Division: ________ Date. ________

Observations, Drawings, Computations:

Answers and Conclusions:

TEST EXPERIMENT 13

1. The ratio of the density of iron at a....deg. C. to that at b....deg. C. is (1) , (2) , (3) , (4) . . . . . . ( )

2. A bar of iron is a....ft. long at b....deg. C. Its length at c....deg. C. (in ft.) is (1) , (2) , (3) , (4) . . ( )

3. The apparent coefficient of cubical expansion of mercury in glass is (1) , (2) , (3) , (4) . . . . ( )

4. The Pennsylvania Railroad has a 4 track line between Pittsburgh and Philadelphia (300 miles). Due to a temperature difference of a....deg. C., the road will have less track in winter than in summer by an amount (in ft.) of (1) , (2) , (3) , (4) . . . . ( )

5. If a glass tube a....sq. cm. in cross-section contains b....cc. of mercury at c....deg. C., the height of the column at d....deg. C. will be (in cm.) (1) , (2) , (3) , (4) . . . ( )

6. At room temperature the inside diameter of a length of copper tubing is a....cm. and the diameter of a steel rod is b....cm. In order to slip the tubing onto the rod, the temperature of the tubing must be increased by (1) , (2) , (3) , (4) . ( )

7. A steel railroad car of a....gal. capacity is filled in Texas with gasoline when the temperature is b....deg. C. When the car arrives in Indiana the temperature is c....deg. C. The capacity of the car has decreased by about (1) , (2) , (3) , (4) gallons . . . . ( )

8. The Indiana purchaser will find that the tank of (7) lacks being full by about (1) , (2) , (3) , (4) gallons . . . . ( )

9. The total space that must be left between rail joints of an a....mile track to allow for an expansion due to a temperature rise of b....deg. C. is (in mi.) (1) , (2) , (3) , (4) . . . . ( )

10. A glass bottle holds a....cc. of mercury at b....deg. C. When the bottle and mercury are at c....deg. C., the number of cc. of mercury that the bottle will hold is (1) , (2) , (3) , (4) . . . . ( )

Name: ______________________ Instructor: ____________________ Division: ________ Date. ________

Observations, Drawings, Computations: ____

Answers and Conclusions: ____

Experiment 14

HEAT OF FUSION OF ICE AND HEAT OF VAPORIZATION OF WATER

Object:

To learn calorimetric technique and to determine the heat of fusion of ice and the heat of vaporization of water.

Apparatus:

Weights, calorimeter, 50° thermometer, 100° thermometer, cup, steam boiler, steam trap, watch.

Theory:

By definition the calorie is the amount of heat necessary to raise the temperature of one gram of water from 15° to 16°C., hence to raise x grams of water from a temperature t_1 to a temperature t_2 takes x $(t_2 - t_1)$ calories. This amount of heat always produces the same change in temperature for the same amount of water provided that there is no change of state occurring between the temperature limits. Likewise a definite amount of heat is required to raise the temperature of x gm. of iron from t_1 to t_2 ; and for any given substance a definite amount of heat is needed to raise a given mass through a given temperature range. It is often convenient to use the amount of heat required to raise one gram of a given body by one degree. This is found by dividing the mean thermal capacity of the body by the mass of the body. This ratio is called the mean thermal capacity of the substance and is denoted by c:

$$c = \frac{Q}{m(t_2 - t_1)} .$$

The ratio of the mean thermal capacity of the substance to that of water is called the specific heat of the substance. This quantity is a pure number; and since, by definition of the calorie, the mean thermal capacity of water is one calorie per gm. per deg. C., the specific heat of a substance is numerically equal to the mean thermal capacity of the substance. Then the amount of heat required to raise the temperature of a body of mass m grams and of thermal capacity c cal./gm./deg. C. from t_1 to t_2 is:

$$Q = mc\,(t_2 - t_1) \text{ calories.} \qquad (1)$$

Also, if the same body cools from the temperature t_2 to t_1 , it gives off the quantity of heat given in eq. (1).

Two bodies, originally at different temperatures, finally come to the same temperature when placed together. The body at the higher initial temperature loses a quantity of heat equal to

$$Q = m_1 c_1 (t_h - t) ,$$

where t_h is the initial temperature and t the final temperature. The cooler body absorbs an amount of heat equal to

$$Q_2 = m_2 c_2 (t - t_c) ,$$

where t_c is the initial temperature.

If this exchange of heat takes place in a region where no heat can enter or leave, i.e., an isolated region, and there is no change of state, then the heat lost by one body must equal that gained by the other body. Hence

$$m_1 c_1 (t_h - t) = m_2 c_2 (t - t_c) .$$

Similarly if n substances are at a temperature t_2 , and m substances at a temperature t_1 , upon contact the m + n substances will be at the same temperature t, and the amount of heat lost by the n substances must equal the amount of heat gained by the m substances if they are in an isolated region. Consequently

$$\sum_{i=1}^{n} m_{1i}\, c_{1i}\, (t_h - t) = \sum_{i=1}^{m} m_{2i}\, c_{2i}\, (t - t_c) .$$

When a substance changes state, e.g., from a solid to a liquid, or liquid to a vapor, or vice versa, heat is absorbed or lost without change in temperature. Since the heat absorbed in changing a unit mass of solid to liquid, or liquid to vapor, is exactly regained in reversing the process, this heat is called the latent heat of vaporization (or condensation), L_f . To account for this heat one must then add to the heat equation a term of the type mL, where m is the mass of substance which changes state.

Any apparatus supplying approximately the conditions of an isolated region is called a calorimeter, and usually consists of a metal cup in which the heat exchange takes place, supported inside a metal jacket by an insulating ring, and fitted with a stirrer and an insulating cover. The inside cup is highly polished to reduce transfer of heat by radiation to a minimum, and the space between the cup and jacket is kept dry to reduce heat loss by conduction through the air.

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Observations, Drawings, Computations:

Answers and Conclusions:

If the calorimeter is below room temperature at the early part of the experiment it gains heat from the surroundings by radiation. If at the latter part of the experiment the calorimeter is at a temperature above that of the room it loses heat by radiation. Hence to get correct values for the latent heat of fusion of ice or heat of vaporization of water corrections due to temperature differences must be made. To do this, temperature readings at intervals of about 30 seconds must be taken, not only during the melting of the ice or condensation of the steam but also for about five minutes before and after these operations.

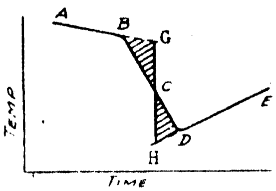

Figure 1

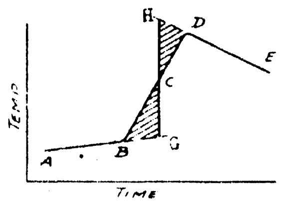

Figure 2

In the case of the heat of fusion of ice a curve like that of Figure 1 is obtained. For the heat of vaporization of steam a curve like that in Figure 2 is obtained. In either case prolong the curves AB and DE and draw the ordinate which divides equally the area formed with the part of the curve, BC. Where the ordinate cuts the prolonged lines, i.e., at G and H, the correct temperatures are given.

Experiment

Part 1

Weigh the cup of the calorimeter and also the stirrer. Knowing the specific heat of the material out of which these are made (Cu or Al), the thermal capacity of the cup and stirrer can be computed. Partially fill the cup with a known mass of water, m_w. Before adding the ice, take a temperature run of the water. Add a known mass, m_i, of ice and stir, always checking the temperature of the mixture every 30 seconds. After a constant temperature has been reached continue the temperature run for 3 minutes. Weigh the cup again to get the mass of ice melted. The amount of heat lost by the water, cup, and stirrer is

$$Q - (m_w c_w + m_c c_c + M_s c_s)\ (t_h - t) \text{ cal.}$$

The heat gained by the ice is

$$Q = m_i L_f + m_i c_w (t - 0^oC.) \text{ cal.}$$

Since the heat lost equals the heat gained

$$(m_w c_w + m_c c_c + m_s c_s)(t_h - t) = m_i L_f + m_i c_w (t - 0^oC.), \tag{2}$$

from which L_f, the heat of fusion of ice, can be calculated.

Calculate L_f using the correct values of temperature as obtained from a plot of your data similar to Fig. 1.

Part 2

Heat water in a boiler during Part 1 of the experiment. If the water in Part 1 is not already about $10^oC.$ below room temperature chill it. Take temperature readings for a few minutes at intervals of 30 seconds before the steam is added. (The steam is ready when steam is shooting out of the steam trap.) Quickly insert the steam tube into the water of the cup. Keep reading the temperature and stir continuously. When the temperature reaches 45^oC, quickly remove the steam jet, but continue the stirring and the recording of the temperature for three minutes more.

Remove the cup and weigh carefully. The difference between the weight at the end of Part 1 and this weight gives the weight of steam condensed. Read the barometer and find the boiling point of water from the table. The heat of vaporization can be computed from

$$(m_w c_w + m_c c_c + m_s c_s)\ (t - t_w) = m_v L_v + m_v c_w (t_v - t), \tag{3}$$

where t_v is the temperature of boiling water, m_v is the mass of vapor condensed.

Using a temperature-time chart like Fig. 2 obtain the correct temperatures and calculate the correct heat of vaporization.

General Precautions:

1. Keep the space between the cup and the jacket dry.
2. Do not splash water out of the cup.
3. Keep cover on except when inserting ice (or steam).
4. Put ice below the stirrer.
5. Keep the thermometer bulb submerged but not touching the ice (or steam jet).
6. Do not allow the temperature to fall below the dew point.
7. Stir continuously.
8. Make all weighings with care.

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Observations, Drawings, Computations: ____________

Answers and Conclusions: ____________

TEST EXPERIMENT 14

1. The number of calories required to change a....gm. of ice at 0 deg. C. to a....gm. of steam at 100 deg. C. is (1) , (2) , (3) , (4) . . . . ( )

2. The number of B.T.U. required to change a....lb. of ice at 32 deg. F. to b....lb. of water and c....lb. of steam at 212 deg. F. is (1) , (2) , (3) , (4) . . . . ( )

3. The melting of a....gm. of ice absorbs from a glass of hot tea (1) , (2) , (3) , (4) calories . . . . ( )

4. A piece of copper with water equivalent a....gm. heated to a temperature of b....deg. C. is placed on a cake of ice at 0 deg. C. The mass of ice melted (in gm.) is (1) , (2) , (3) , (4) . . . . ( )

5. A....gm. of steam at the boiling point are turned on a large block of ice at 0 deg. C. The mass of ice melted is (in gm.) (1) , (2) , (3) , (4) . . . . ( )

6. A piece of ice at 0 deg. C. weighing a....gm. is placed in a large chamber filled with steam at 100 deg. C. The amount of steam condensed is (in gm.) (1) , (2) , (3) , (4) . . ( )

7. A piece of ice weighing a....gm. is placed in a calorimeter (water equivalent b....gm.) containing c....gm. of water at d.... deg. C. The final temperature of the mixture (in deg. C.) will be (1) , (2) , (3) , (4) . . . . ( )

8. In an experiment to measure the heat of fusion, the temperature of a....gm. of water (including the water equivalent of the calorimeter) is lowered from b....deg. C. to c....deg. C. by the addition of d....gm. of ice. This set of data gives for the heat of fusion a value (in cal./gm.) of (1) , (2) , (3) , (4) . . ( )

9. Steam of mass a....gm. at 100 deg. C. is turned into a calorimeter (water equivalent b....gm.) containing C....gm. of water at d....deg. C. The final temperature of the mixture (in deg. C.) will be (1) , (2) , (3) , (4) .... ( )

10. In a steam radiator system steam (s.h. 0.5) is brought in at a temperature of a....deg. C. and sent out as water at b....deg. C. If c....gm. of steam are sent into the system each second, the amount of heat evolved per sec. (in cal.) is (1) , (2) , (3) , (4) . . . . ( )

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Observations, Drawings, Computations:

Answers and Conclusions:

Experiment 15

THE SPECIFIC HEAT OF A SOLID

Object:

To measure the specific heat of a solid by the method of mixtures.

Apparatus:

500 grams lead shot; 100 grams aluminum shot; 1 copper calorimeter; boiler; dipper; 0-100° thermometer; 0-50° tenth-degree thermometer; Bunsen burner; platform balance.

Theory:

Definitions:

1. A calorie is the amount of heat which will change the temperature of one gram of water from 15°C. to 16°C. This is more generally (but not so exactly) defined as "the amount of heat which will raise the temperature of 1 gram of water 1°C."

2. The mean thermal capacity of a substance is equal to the number of heat units required to raise the temperature of a unit mass of the substance one degree.

3. The specific heat is the ratio of the mean thermal capacity of a substance to that of water at 15°C.

The mean thermal capacity of a substance is then numerically equal to the specific heat.

From the above it can be seen that the thermal capacity of water in the metric system is 1 cal./gm./deg °C, and hence the specific heat of a substance is numerically eaual to "the number of calories which will change the temperature of one gram of that substance by 1°C." Definitions 2 and 3 may be applied to the English system as well. The British Thermal Unit is defined as "the amount of heat required to raise the temperature of one pound of water from 60° to 61° Fahrenheit." Then the mean thermal capacity and the specific heat remain the same despite the change in systems.

One other definition is required in this experiment. The water equivalent of a body is given by the product of the mass of a body and the thermal capacity of the substance. It may be thought of as the mass of water which will require the same amount of heat to raise its temperature 1° as that required by the body itself. The metal containing the water will always have the same temperature as the water. Once the water equivalent of the metal cup is known, one can add this value directly to the mass of the water and consider this sum as the effective mass of water.

The method to be used is called the Method of Mixtures. Its success depends on the fact that when two bodies at different temperatures are brought together, the amount of heat lost by the one equals the amount of heat gained by the other body (always assuming no loss of heat by radiation). In this experiment a metal is heated to about 95°C. by being heated dry in a cup immersed in boiling water. The dry metal is then poured into a measured amount of cold water and the metal and water come to equilibrium at some intermediate temperature. The specific heat can be found from the following equation:

Heat lost = heat gained,

$$m_x(t_m - t_f)\ c = (m_w + e)\ (t_f - t_w)\ 1,$$

where mx = mass of the metal; m_w = mass of the water, e = water equivalent of calorimeter; t_f = final temperature of the metal and water; t_m = initial temperature of the metal; t_w = initial temperature of the water; c = mean thermal capacity of the unknown; thermal capacity of water = 1.

The heat gained or lost by radiation from or to the surroundings will be least if the initial temperature of the water is chosen a few degrees below room temperature and the relative amounts of water and metal are taken so that the final temperature of the mixture is a few degrees above room temperature. The suggested amounts will approximate this condition.

Experiment

Part 1

Fill the copper boiler half full of water and start heating. Be sure the boiler has plenty of water in it at all times during heating.

Weigh to the nearest gram about 500 grams of lead shot and place in the copper dipper and set the latter in the boiler. Insert the 100° thermometer carefully so that the bulb is well covered by the metal. BE SURE THAT THE THERMOMETER USED HERE READS AT LEAST 100°C.

While the shot is heating, weigh the calorimeter (dry); this is the inner cup in which the mixing is done. Pour into this cup about 150 grams of tap water and weigh again to get the weight of the water (to the nearest gram).

When the temperature in the dipper has ceased to rise (between 95° and 100°), read the temperature of the cold water with a tenth-degree thermometer, remove this thermometer from the water, check accurately the temperature of the hot shot, and without loss of

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Observations, Drawings, Computations:

Answers and Conclusions:

time pour the hot shot from the dipper into the calorimeter.

Let the shot and water stand for about ten or fifteen seconds and then, being careful not to let the hot shot run the thermometer above the top of its scale, stir metal and water thoroughly with the tenth-degree thermometer and observe the highest equilibrium temperature; that is, the temperature at which the thermometer when pushed well down into the shot begins to go down slowly and regularly.

Record all the necessary readings and calculate the specific heat of lead shot.

Part 2

Repeat for aluminum, using 100 grams of aluminum in 150 grams of water.

What factors in this experiment produce errors in your values for specific heats? In which direction do they tend to shift your values?

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Observations, Drawings, Computations:

Answers and Conclusions:

TEST EXPERIMENT 15

1. The rise in temperature when a....gm. of copper (s. h. = 0.09) at b....deg. C. is added to c....gm. of water at d....deg. C. (in degrees C.) is (1) , (2) , (3) , (4) . . . ( )

2. If it takes a....min. to heat b....gm. of soup of sp. heat c....from d....deg. to e....deg. C. and the stove is f....% efficient, then the stove must supply heat at the rate of (1) , (2) , (3) , (4) cal./min. . . . . ( )

3. When a....gm. of aluminum at b....deg. C. is dropped into c....cc. of water in a calorimeter of water equivalent d....gm., both calorimeter and water at e....deg. C., the temperature is raised to f....deg. The amount of heat wasted (in cal.) is (1) , (2) , (3) , (4) . . . . ( )

4. The water equivalent of the mercury in a glass thermometer is a....gm. If it reads b....deg. C. before being immersed in c....gm. of water at d....deg. C., it will read after immersion (1) , (2) , (3) , (4) . . . . ( )

5. A block of metal weighs a....lb. and its water-equivalent is b....B.T.U. The specific heat of the metal is (1) , (2) , (3) , (4) . . . . ( )

6. A....cc. of alcohol (sp.gr.=0.8 and s.h.=0.6) at b...deg. C. is poured into a graduate whose water equivalent is c....gm. at room temperature (25 deg.c.). The alcohol will be cooled (1) , (2) , (3) , (4) degrees C. . . . . ( )

7. A vessel of lead (s.h.=0.033) weighing a....gm. has the same water equivalent as a copper (s.h.=0.09) vessel weighing (in gm.) (1) , (2) , (3) , (4) . . . . ( )

8. It is desired to raise the temperature of a....lb. of water at b....deg. F. to its boiling point by immersing in it c...lb. of copper (s.h.=0.09). The temperature of the copper (in deg. F.) must be (1) , (2) , (3) , (4) . . . . ( )

9. A tin vessel of a....gm. contains b....gm. of water at c.... deg. C. If the temperature of water and vessel rises d....deg. C. upon the addition of e....cal. of heat, then the specific heat of tin is (1) , (2) , (3) , (4) . . . . ( )

10. The following pieces of metal are added to a....cc. of water in a container whose water equivalent is b....gm.: c....gm. of lead (s.h.=0.33) at d....deg. C., e....gm. of copper (s.h.=0.093) at f....deg. C., and g....gm. of zinc (s.h.=0.095) at h....deg. C. If the final temperature is i....deg. C., the original temperature (in deg. C.)of the water and container was (1) , (2) , (3) , (4) . . . . ( )

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Observations, Drawings, Computations: ______________________

Answers and Conclusions: ______________________

Experiment 16

COEFFICIENT OF EXPANSION OF A SOLID

Object:

To determine the coefficient of linear expansion of a metal rod.

Apparatus:

Expansion apparatus, two 100° thermometers, steam boiler.

Theory:

In this experiment the coefficient of linear expansion of a metal rod is determined. A metal rod, when heated uniformly over its entire length, expands and every unit length of the rod becomes longer. The increase in length of each unit length for one degree rise in temperature is called the coefficient of linear expansion. This coefficient depends upon the temperature scale used, but not upon the unit of length employed. This coefficient can be expressed as:

$$\alpha = \frac{\ell}{L\,t}, \qquad (1)$$

where α = coefficient of linear expansion, L = the original length, ℓ = change in length produced by the temperature change t.

The apparatus used is shown in Figure 1. Measure the length of the rod to the nearest millimeter with a meter stick. Place the rod R inside the jacket J so that one end is placed firmly against the end plate B. Bring the micrometer screw M into contact with the other end of the rod and record the reading. Screw out the micrometer at least one centimeter to allow for the expansion. Insert a 100° thermometer into the opening T and record the initial temperature. Leave the thermometer in place. Pass steam from a boiler into the jacket through one of the openings in the jacket. Continue to heat the rod until the temperature reaches a constant value. Then bring the micrometer screw into contact with the end of the rod and record the reading. Record the temperature.

From the measured change in length, change in temperature, and original length calculate the coefficient of linear expansion of the rod from equation (1).

Repeat the measurements and calculation for a rod of different material.

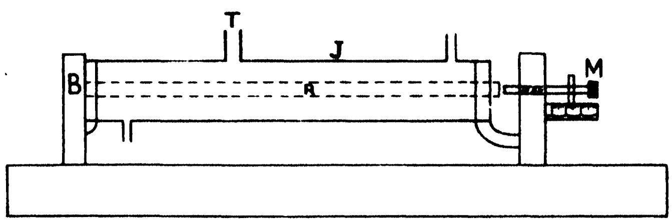

Figure 1

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Observations, Drawings, Computations:

Answers and Conclusions:

1. The coefficient of linear expansion of the steel in a bridge is a....per degree C. If the maximum change in temperature is b....°C, and the bridge is c....ft. long at the minimum temperature, the change in length of the bridge (in ft.) is: (1) , (2) , (3) , (4) . . . . ( )

2. A rod has a cross section of a....sq. cm. (Young's Modulus = 10^{10} dynes/sq. cm.; $\alpha = 10^{-5}$ /°C.) The force required to extend the rod the same amount as the expansion would produce by heating it through b....°C. (in dynes) is: (1) , (2) , (3) , (4) ( )

3. The cables of a suspension bridge are a....ft. long, and the coefficient of linear expansion of the steel of which they are constructed is b....per °F. If the maximum and minimum temperatures to which they are exposed are c...°F. and d...°F., respectively, the maximum change in length of the cables (in ft.) is: (1) , (2) , (3) , (4) . . . . ( )

4. A metal bar is a....cm. long at b....degrees C. and c....cm. long at d....degrees C. Its average coefficient of linear expansion per degree C. between these temperatures is: (1) , (2) , (3) , (4) . . . . ( )

5. A wire a....sq. in. in cross-section (Young's modulus = 10^6 lbs./ sq. in.) is held from contracting when the temperature is reduced from b...°F. to c...°F. The tension in the wire is d....pounds. The average coefficient of linear expansion is: (1) , (2) , (3) , (4) ,. . . . . ( )

6. Two metal rods are arranged to compensate for changes of length due to temperature changes. The distance between the free ends will remain constant. The coefficient of linear expansion of the short rod is a....per degree F. and its length is b....ft. If the long rod is c....ft. long its coefficient of linear expansion per degree F. is: (1) , (2) , (3) , (4) . . . ( )

7. If a railroad were made around the earth at a latitude of a.... degrees and the rails were all welded together, (coef. of linear expansion = b..../°F) (radius of earth at equator = b....mi.) the rails would rise from the earth, with a change of temperature of c....°F., a distance (in ft.) of: (1) , (2) , (3) , (4) , ... ( )

8. A wire of 0.01 sq. in. cross-section, with coef. of linear expansion of a..../°F., Young's Modulus of b....lb. per sq. in. and d....ft. long, hangs freely with one end attached to a rigid beam. A weight of e....lb. is now fastened to its lower end and then the temperature rises f....degrees F. The length of the wire increases (in ft.): (1) , (2) , (3) , (4) ,. . . ( )

9. If an error of a....% is made in measuring the length of the rod in this experiment, b....% in measuring the change in length and c....% in measuring the temperature change, the total error in computing the coefficient of expansion (in %) is: (1) , (2) , (3) , (4) . . . . ( )

10. If the coefficient of linear expansion of a metal is a..../ degree F, its linear coefficient of expansion (per degree C) is: (1) , (2) , (3) , (4) . . . . ( )

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Observations, Drawings, Computations:

Answers and Conclusions:

Experiment 17

THE ELECTROSCOPE AND COULOMB'S LAW

Object:

To study the laws of attraction and repulsion between charged bodies.

Apparatus:

Electroscope, pith balls, hard rubber and glass rods, wool and silk.

Theory:

An electroscope is a device for detecting electric charge. The form which is to be used here consists of a rod to which is attached near the lower end one end of a metallic foil capable of rotating in a vertical plane about the point of attachment. To the upper end of the rod is attached a metallic disc. In order to shield the electroscope from stray electric fields, the lower portion is enclosed in a metal case. The rod is insulated from the case by a sulphur cylinder set in the top of the case serving to hold the rod in place. A cover is provided which can sit over the metallic disc to shield it. A window is provided in the case so that the metal foil can be observed. The shielding action is an application of the ice pail experiment of Faraday in which he showed that a charge cannot exist on the inner surface of a cavitous conductor.

The action of the electroscope depends upon the fundamental electric property that two similarly charged bodies repel each other. Since the rod and the leaf are in metallic connection, a charge on one will be shared by the other and so a force of repulsion will exist. The deflection of the leaf then depends upon the charge and the mass of the leaf.

Such an electroscope may be charged in two ways, by conduction and by induction. To charge by conduction an electrified body is brought into contact with the electroscope. Upon contact the charge is shared with the electroscope and the leaf diverges.

To charge the electroscope by induction the charged body is brought near the metal plate. In this case the leaves diverge just as they did before. Now ground the electroscope by touching the plate with a finger still having the charged body close to the plate. The leaf is now collapsed. Remove the finger and then remove the charged body. The leaf diverges, showing the electroscope to be charged.

A pair of pith balls may also be used to demonstrate the phenomenon of electrification and to show a good example of Coulomb's Law. The pith ball electroscope consists of a pith ball covered with a metallic conductor and suspended from a support by means of a silk thread. If a pair of pith balls are charged by bringing them in contact with a charged body and then touching them together, they will each have a charge of the same kind and magnitude. Consequently, they will tend to repel each other. One can measure the charge on the pith balls in the following way:

Bring the points of suspension of the pith balls together and see that the lengths of the suspending cords are the same. Let the charge on each pith ball be Q, its mass m, and the angle between the strings 2θ, and the distance between the pith ball centers r, the length of the strings ℓ.

The force urging the pith balls apart is by Coulomb's Law:

$$F = \frac{Q^2}{r^2} .$$

The restoring force due to the weight of the pith ball is $F = mg \tan\theta$. Equating these and solving for Q, one obtains $Q = r\sqrt{mg \tan\theta}$.

Experiment

Part I

Record pictorially all observations as well as write them down. Follow directions in detail.

(a) Charge the electroscope by conduction with the hard rubber rod. (A charge may be brought on the rod by rubbing it with felt.) Ground the electroscope.

(b) Charge the electroscope by conduction using the glass rod. Bring the charged hard rubber rod near the electroscope which has been charged with the glass rod. Remove the rubber rod. Touch the rubber rod to the charged electroscope.

(c) Charge the electroscope by conduction using the rubber rod. Bring the charged glass rod near the electroscope. Remove it. Touch the electroscope with the charged rubber rod.

(d) Charge the electroscope by induction using the rubber rod. Bring the charged rubber rod near the electroscope. Remove it. Touch it to the electroscope.

(e) Charge the electroscope by induction using the rubber rod. Bring the charged glass rod near the electroscope. Remove it. Touch it to the electroscope.

Repeat (d) and (e) but charge the electroscope by induction using the glass rod.

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Observations, Drawings, Computations: ______________________

Answers and Conclusions: ______________________

Part 2

Charge the pith balls equally using the rubber rod. Bring the points of suspension together and measure their separation. Calculate the charge assuming each pith ball to have a weight of 30 milligrams.

Assuming the charge on the rubber rod to be negative and a charge which tends to neutralize the effect of a negative charge, to be a positive charge, what is the sign of the charge acquired by a glass rod rubbed with silk?

For Part I make a table showing the original sign of the charge on the electroscope, the operation performed, and the resulting sign on the electroscope as well as the sign of the increase in the charge acquired in each case.

Explain the operation of charging by induction on the basis of the electron hypothesis and the potential theory.

Name:____________________ Instructor:________________ Division:________ Date.______

Observations, Drawings, Computations:

Answers and Conclusions:

TEST EXPERIMENT 17

1. Two equal point charges separated by a....cm. in air repel each other with a force of b....dynes. The charges may be (in e.s.u.) (1) , (2) , (3) , (4) . . . . ( )

2. The charges in problem (1) are surrounded by a substance of specific inductive capacity a.... With no other charges present the force will now be (in dynes) (1) , (2) , (3) , (4) . . . . ( )

3. Two equally charged balls weighing a....dynes each repel each other with a force of b....dynes when separated by c....cm. in air. The charge on each is (in e.s.u.) (1) , (2) , (3) , (4) . . . . ( )

4. The angle between the string holding each ball in problem (3) and the vertical is an angle given by (1) , (2) , (3) , (4) . . . . ( )

5. A point charge of a....e.s.u. repels an unknown point charge b....cm. away with a force of c....dynes. The charge (in e.s.u.) of the unknown is (1) , (2) , (3) , (4) . . . . ( )

6. Two equal point charges of a....e.s.u. each are separated by a distance of b....cm. and are surrounded by a substance other than air. If the force of repulsion is c....dynes, the specific inductive capacity is (1) , (2) , (3) , (4) . . . . . ( )

7. Two equally charged pith balls weighing a....dynes apiece are suspended from a common point by threads b....cm. long and are separated by a distance of c....cm. in air. The charge on each ball (in e.s.u.) is (1) , (2) , (3) , (4) . . . ( )

8. A unit positive charge midway between charges of a....e.s.u. and b....e.s.u. that are c....cm. apart in air is acted upon by a force (in dynes) of (1) , (2) , (3) , (4) . . . ( )

9. Two point charges of a....e.s.u. each repel each other in air with a force of b....dynes. The distance between them(in cm.) is (1) , (2) , (3) , (4) . . . . ( )

10. If the charges of problem (9) are separated by a substance of specific inductive capacity a....and the force is the same, then the distance between them (in cm.) must be (1) , (2) , (3) , (4) . . . . ( )

Name: Instructor: Division: Date.

Observations, Drawings, Computations:

Answers and Conclusions:

$$F = \frac{2\, m_1\, m_2}{d^2 + \ell^2} \quad \frac{\ell}{\sqrt{d^2 + \ell^2}}. \qquad (7)$$

Simplification gives:

$$F = \frac{2\, m_1\, m_2\, \ell}{(d^2 + \ell^2)^{3/2}}, \text{ or} \qquad (8)$$

$$\frac{F}{m_1} = H_m = \frac{2m_2\, \ell}{(d^2 + \ell^2)^{3/2}}. \qquad (9)$$

Then

$$\frac{H_m}{H_e} = \frac{2m_2\, \ell}{H_e\,(d^2 + \ell^2)^{3/2}} = \tan\phi. \qquad (10)$$

On substitution of the constant K defined by eq. (5), the above becomes:

$$2(d^2 + \ell^2)^{3/2} \tan\phi = \frac{4m_2 \ell}{H_e} = K. \qquad (11)$$

In measuring the angle of deflection ϕ it is necessary that the compass be tapped slightly in order to see that the needle is not sticking.

The distance ℓ is found by placing the magnet in an east-west direction and then using the compass to locate the poles.

Experiment

Part 1

Place the meter stick in the east-west direction, and place the magnet lengthwise on the meter stick with the north pole toward the compass. Make four sets of observations recording the distánce d and the corresponding angle of deflection θ for values of θ ranging from 20° to 60°. By means of formula (5) the values of the arbitrary constant K are calculated, and the average value found.

The magnet is then turned around so that the south pole is toward the compass and the above procedure is followed for the same values of d. The values of K and the average value are obtained as before. Mark the position of the compass with a "cross" chalk mark.

Part 2

The meter stick is then placed in the north-south direction and the magnet is placed crosswise on the meter stick north of the compass. With the compass on the chalk mark as before, make four sets of observations, recording the value of d and its corresponding angle of deflection ϕ for values of θ ranging from 20° to 60°. By means of formula (11) the values of K are calculated and the average value found.

The poles of the magnet are then reversed and the above procedure is repeated for four values of d in the same range. The values of K and its average value are obtained as before.

The four mean values of K thus obtained should be nearly equal.

Part 3

Average the mean values of K obtained by means of equations (5) and (11). Calculate the pole strength of the magnet where $H_e = .2$ oersted.

Name: Instructor: Division: Date.

Observations, Drawings, Computations:

Answers and Conclusions:

TEST EXPERIMENT 18

1. Two identical bar magnets are placed so that the four poles lie at the corners of a square a....cm. on a side. If the poles have a strength of b....units each, the force (in dynes) between the two magnets is (1) , (2) , (3) , (4) .... ( )

2. A pole of a....units is placed in a magnetic field of b....oersteds; the force (in dynes) acting on the pole will be (1) , (2) , (3) , (4) .... ( )

3. Two poles of a magnet are a....cm. apart and each has a strength of b....unit poles. The magnitude of the field intensity outside the magnet and on its axis c....cm. from the nearer pole is (in oersteds) (1) , (2) , (3) , (4) .... ( )

4. In order that two like magnetic poles of equal strength (a.... unit poles each) repel each other with a force of b....dynes, the separation of the poles (in cm.) must be (1) , (2) , (3) , (4) .... ( )

5. If two poles (strengths; N-a....units, S-b....units) have a force of attraction between them of c....dynes when separated by a distance of d....cm. in a permeable substance, then the permeability of the substance is (1) , (2) , (3) , (4) .... ( )

6. If two like magnetic poles are placed a....cm. apart in a vacuum, the magnitude of the force acting upon either pole, if the pole strengths are b.... and c....units respectively, is (in dynes) (1) , (2) , (3) , (4) .... ( )

7. If a pole of a....units is placed in a uniform magnetic field, it experiences a force of b....dynes. As a consequence the magnitude of the strength of the magnetic field (in oersteds) must be (1) , (2) , (3) , (4) .... ( )

8. Two like magnetic poles are placed a....cm. apart in a substance of permeability b.... The magnitude of the force acting between the poles, if the pole strengths are c....and d....units respectively, is (in dynes) (1) , (2) , (3) , (4) .. ( )

9. A compass needle is placed in a uniform magnetic field having an intensity of a....oersteds. Each pole of the needle has a strength of b....units and the distance between the poles is c....cm. If the axis of the needle makes an angle of d....deg. with the direction of the field, the magnitude of the torque acting upon the compass (in dyne-cm.) is (1) , (2) , (3) , (4) ...... ( )

10. The poles of a magnet are a....cm. apart and have a strength of b....unit poles each. The magnitude of the magnetic field strength at a point outside the magnet and on its perpendicular bisector c....cm. from the magnet is (in oersteds) (1) , (2) , (3) , (4) .... ( )

Name: ______ Instructor: ______ Division: ______ Date. ______

Observations, Drawings, Computations: ______

Answers and Conclusions: ______

Experiment 19

MECHANICAL EQUIVALENT OF HEAT BY AN ELECTRICAL METHOD (JOULE'S LAW)

Object:

To study the heating effect of a current of electricity and measure the mechanical equivalent of heat.

Apparatus:

Heating unit, calorimeter, 50° thermometer, clock, scales and weights.

Theory:

The electric current strength is defined as the rate of flow of electricity. When a current flows in a conductor with resistance the effect is to heat the conductor.

Joule's Law states that the equivalent work W done when a current heats a conductor is equal to the heat in calories multiplied by the mechanical equivalent of heat J; that this work is proportional to the square of the current I, the resistance R of the conductor and the time t that the current flows.

$$W = JQ = I^2Rt \quad (1)$$

where Q = heat in calories.

An electrical heating unit is used to raise the temperature of water in a calorimeter cup. The heat (Q cal.) gained by the water and the calorimeter is found by measuring the mass of the water, adding to it the water equivalent of the apparatus, and multiplying this sum by the measured temperature change of the water. The work done (in the form of electrical energy) is determined by measuring the current, the resistance of the heating unit and the time that the current flows. The mechanical equivalent of heat is then found from eq. (1), Joule's law of heating. In this equation J is the electrical equivalent of heat in joules/cal., Q is the heat developed in calories, I is the current in amperes, R is the resistance in ohms, and t is the time in seconds.

Experiment

Part 1

Connect the heating unit to a switch in series with a battery (or other source of e.m.f.) and ammeter. Do not close the switch until the circuit has been checked by the instructor.

Put about 200 gm. of water into the calorimeter cup. The water should be about 4°C below room temperature; if necessary, cool the cup and water in an ice chest. Put the cup into the calorimeter and place the heating unit, stirrer, and thermometer in position. Do not close the switch yet.

Read the temperature of the water every half minute for about 25 minutes in all, keeping the water well stirred. After stirring the water about 5 minutes, close the switch, noting the time. Read the ammeter every minute as long as the current flows. When the temperature of the water is about 4°C above room temperature, i. e. as far above room temperature as the initial temperature was below, open the switch and again note the time. Continue thermometer readings and stirring about 5 minutes longer. The water equivalent of the cup, stirrer and heater and the resistance of the heating unit are obtained from the apparatus.

Calculate the value of J from equation (1) without making any radiation corrections.

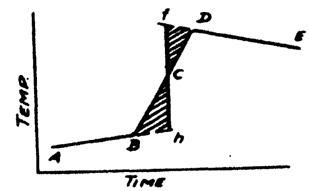

Figure 1

Part 2

Plot a curve with temperatures as ordinates and times as abscissae. A curve similar to A B C D E will be obtained, where B is the point at which the current began to flow. Project AB and ED and draw the ordinate which equally divides the shaded area. The corrected temperatures are indicated at the points where this ordinate intersects the curve.

Use the corrected temperatures and find a corrected value of J.

Make a diagram of the circuit.

Calculate the value of J in foot-pounds per B.T.U.

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Name: Instructor: Division: Date.

Observations, Drawings, Computations:

Answers and Conclusions:

TEST EXPERIMENT 19

1. To raise the temperature of a....liters of water b....deg. C. with a heating element that can deliver c....joules of energy per second will require a time (in seconds) of (1) , (2) , (3) , (4) . . . . ( )

2. The expense of illuminating a hallway, so far as the actual cost of power consumed goes, with a lamp that draws a current of a.... amperes from a b....volt A.C. line for c....hours, if the cost of electricity is d...cents per kw. -hr., is (1) , (2) , (3) , (4) . . . . ( )

3. The power dissipated by a certain resistor is a....watts. If the value of its resistance in ohms is b...., then the current (in amp.) flowing through it is (1) , (2) , (3) , (4) . . . . ( )

4. An electric motor does a....ft.-lb. of work in b....hours. The power rating of the motor (in hp.) (1 hp. is 33,000 ft. lb./min.) is (1) , (2) , (3) , (4) . . . . ( )

5. If a....amperes flow for b....minutes through a resistance of c....ohms, the heat (in cal.) developed is (1) , (2) , (3) , (4) . . . . ( )

6. In problem (5) the work in joules done by the current is (1) , (2) , (3) , (4) . . . . ( )

7. A heating element is to raise a....gm. of water from 20°C to 100°C in b....seconds. If the element is to operate on c....volts, its resistance (in ohms) must be (1) , (2) , (3) , (4) . . . . ( )

8. If electrical energy cost a.... cents per kw.-hr., the cost (assuming 100% efficiency) of heating b....gm. of water from c.... °C to d....°C on an electric stove is (1) , (2) , (3) , (4) . . . . ( )

9. A....volts are impressed across a heating coil of b....ohms resistance. If the heating coil is submerged in c....grams of water for d....minutes, the change in temperature of the water is (1) deg. F., (2) deg. C., (3) deg. F., (4) deg. C., . . . ( )

10. When a heating coil of a....ohms resistance is placed in a pipe through which water is flowing at the rate of b....cc./sec., the temperature of the water is increased c....deg. C. after it has passed the coil. The current flowing in the coil is (in amp.) (1) , (2) , (3) , (4) . . . . ( )

Name: ______________________ Instructor: ______________________ Division: __________ Date. __________

Observations, Drawings, Computations: ______________________

Answers and Conclusions: ______________________

Experiment 20

OHM'S LAW

Object :

To study the relation between resistance, e.m.f. and current for conductors made of solids and gases.

Apparatus:

Ammeter, voltmeter, resistances, rheostat, batteries, and connecting wires.

Theory:

In solid conductors the moving free electrons constitute the current; in liquid electrolytes, the moving positive and negative ions constitute the current; in gases, the charges may be carried by electrons, protons and positive or negative ions. In all cases of conduction, the source of the electric carriers determines to a great extent the character of electric conduction. Ohm's Law,

$$I = \frac{E}{R},$$

is followed where the conductors are electrolytes, metallic solids or liquids if the current density is not too great (amperes per sq. cm.); with gases, the law is very seldom followed.

Where there is a source of e.m.f. E sending current around a circuit, Ohm's Law states that the current I is equal to the total e.m.f. E divided by the total resistance R, or that the e.m.f. divided by the current is a constant which is equal to the resistance of the circuit.

If there is no source of e.m.f. in a current-bearing conductor ab (see Figure 1), then the drop in electric potential V_{ab} along the conductor divided by the current I is a constant and is equal to the resistance r_e.

$$\frac{E}{I} = R = r_1 + r_e \quad , \qquad (1)$$

$$\frac{V_{ab}}{I} = r_e \quad ,$$

r_e = external resistance

r_i = internal resistance.

If the current is variable and the circuit contains inductance or capacitance, then Ohm's Law holds only for instantaneous values since back e.m.f.'s are generated and have to be considered.

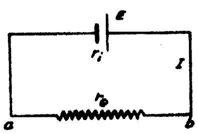


Figure 1

Experiment

Part 1

Solid Conductors. --Each student (or pair) of a group connects the first sample solid conductor in a switch circuit arranged as in Figure 2 and opens the switch. The current from the battery E then flows through each resistance (r_1 , r_2 , r_3 .....), through the Instructor's ammeter A and back to the battery.

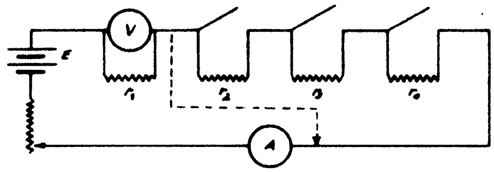


Figure 2

The electric potential is now measured with a voltmeter by each student (or pair). The current is read from the Instructor's ammeter A. The Instructor changes the current and the above process is repeated several times. The voltmeter readings are to be divided by the ammeter readings to see if Ohm's Law is followed. Volts divided by amperes gives ohms resistance.

Several samples of conductors are tested in this way. The results are to be tabulated. Does Ohm's Law hold in this case?

Part 2

Gases.--An inclosed electric arc is formed between two carbon electrodes and the current and e.m.f. are measured as the current is changed. A curve is plotted with amperes as ordinates and volts as abscissae. Discuss the characteristics of the curve and the nature of the conduction in the arc.

The Instructor will give specific directions in this part of the experiment.

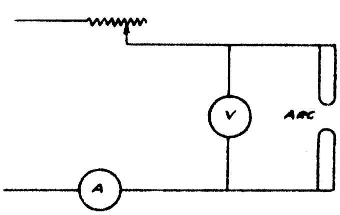


Figure 3

Name: ______________________ Instructor: ______________________ Division: __________ Date. __________

Observations, Drawings, Computations: ______________________

Answers and Conclusions: ______________________

1. When a....volts are applied across the terminals of two lamps connected in series (the resistance of one being twice the other), it is observed that a current of b....amp. flows. Hence the smaller of the resistances (in ohms) is (1) , (2) , (3) , (4) . . . . ( )

2. A battery which has an e.m.f. of a....volts and an internal resistance of b....ohms is connected in series with an external resistance of c....ohms. The current that flows through the external resistance is (in amp.) (1) , (2) , (3) , (4) . ( )

3. If a wire of negligible resistance is put across the terminals of a dry cell of a....ohms internal resistance and b....volts e.m.f., the current that will momentarily flow is (in amp.) (1) , (2) , (3) , (4) . . . . ( )

4. A storage battery consists of 3 cells, each of e.m.f. a....volts and internal resistance b....ohms, all connected in series to a resistance coil. If the current in the coil is c....milliamperes, the resistance of the coil (in ohms) is (1) , (2) , (3) , (4) . ( )

5. A dry cell of one ohm internal resistance sends a current of a....amp. through an external resistance of b....ohms. The e.m.f. of the dry cell (in volts) is (1) , (2) , (3) , (4) . ( )

6. The maximum current that can pass through a given ammeter without damaging it is 5.00 amperes. If this ammeter is connected in a circuit containing a a....volt cell, the total resistance of the circuit (in ohms) must be at least (1) , (2) , (3) , (4) . . . . ( )

7. A battery of e. m. f. a....volts and an internal resistance of b....ohms is placed in series with an external resistance of c.... ohms. The current flowing in the external circuit is (in amp.) (1) , (2) , (3) , (4) . . . . ( )

8. It is desired to use an a....volt lamp on a b....volt D.C. line. The amount of resistance necessary to include in series with this lamp to cut down the current to its maximum safe value of c....amp. is (in ohms) (1) , (2) , (3) , (4) . . . . ( )

9. A battery with an internal resistance of a....ohms is connected in series with an external resistance of b....ohms. The current flowing in the circuit is d....amp. The e.m.f. of the battery (in volts) is (1) , (2) , (3) , (4) . . . . ( )

10. A battery having an e.m.f. of a....volts and an internal resistance of b....ohms delivers current to an external resistance of c....ohms. The voltage drop across the external resistance is (1) , (2) , (3) , (4) . . . . ( )

Name: ______________________ Instructor: ______________________ Division: __________ Date. __________

Observations, Drawings, Computations: ______________________

Answers and Conclusions: ______________________

Experiment 21

WHEATSTONE BRIDGE AND RESISTANCES IN SERIES AND PARALLEL

Object:

To study the theory of the Wheatstone Bridge and to measure resistances by means of it.

Apparatus:

Wheatstone Bridge, standard resistance boxes, unknown resistances.

Theory:

According to Ohm's Law, the resistance of a solid conductor can be measured by determining the potential difference across the resistance and the current flowing through it. But in many cases it is more accurate to compare the unknown resistance with that of a known or standard resistor. One of the comparison methods is that of the Wheatstone bridge.

The Wheatstone bridge is shown schematically in Figure 1. R_1, R_2, R_3, and R_4 are variable standard resistances boxes. Essentially the bridge is two resistances ($R_2 + R_2$ and $R_3 + R_4$) in parallel. For any point B on the branch ABC there exists a point D on the branch ADC which is at the same potential. This is shown by the fact that a sensitive galvanometer connected across BD shows no deflection, thus indicating no flow of current. Since the potential at B, V_B, is equal to the potential at D, V_D, it follows that:

$$V_A - V_B = V_A - V_D \text{, and}$$

$$V_B - V_C = V_D - V_C .$$

But

$$V_A - V_B = R_1 I_1 ,$$

$$V_A - V_D = R_3 I_3 ,$$

$$V_B - V_C = R_2 I_2 = R_2 I_1 ,$$

$$V_D - V_C = R_4 I_4 = R_4 I_3 .$$

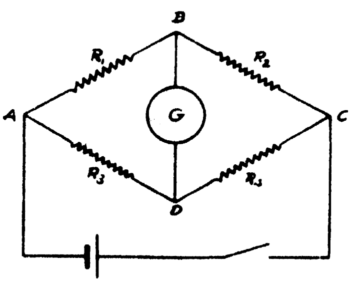


Figure 1

Substitution and division give:

$$R_1 I_1 = R_3 I_3 ,$$

$$R_2 I_1 = R_4 I_3 .$$

$$\frac{R_1}{R_2} = \frac{R_3}{R_4} . \qquad (1)$$

In the slide-wire Wheatstone bridge (Figure 2), the resistances R_3 and R_4 are made of lengths of wire of uniform cross-section. If R_3 is of length a and R_4 of length b, then

$$R_3 = \frac{\rho a}{A} \text{ and } R_4 = \frac{\rho b}{A} .$$

Substitution of the above expressions into eq. (1) gives:

$$\frac{R_1}{R_2} = \frac{a}{b} . \qquad (2)$$

where a is the distance from A to D, the position of the slide at which the galvanometer shows no deflection, and b is the distance DB. Therefore, if R_2 is known and the lengths a and b are measured, R_1 can be calculated from the relation:

$$R_1 = R_2 \frac{a}{b} . \qquad (3)$$

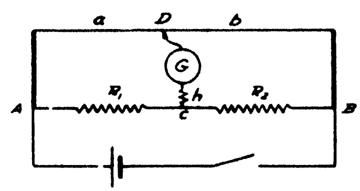


Figure 2

Experiment

Part I

To test the theory of the bridge and its accuracy, set up a slide wire Wheatstone Bridge as shown in Figure 2, and put a resistance of 10 ohms in R_1, 15 ohms in R_2, and 1000 ohms in h (See Instructor). Find the point D on the slide wire for which no current flows through the galvanometer. (To save the battery do not leave the battery key on longer than necessary to take readings. Make contact at D by tapping momentarily and watch for the motion of the pointer. Near A it will deflect in one direction, and near C in the opposite direction. Why? The point of no deflection is somewhere in between.) Compare the ratio R_1 / R_2 with the ratio a/b. Repeat with 2 and

Name: ______________________ Instructor: ______________________ Division: __________ Date. ______

Observations, Drawings, Computations:

Answers and Conclusions:

3 ohms in R_1 and R_2 respectively. Repeat with a different ratio between R_1 and R_2. What is true with regard to the ratios R_1/R_2 and a/b ? What would happen if R_1 and R_2 were interchanged?

Part 2

Remove R_2 from the bridge and substitute the unknown resistance X_1. Set the slider at the middle of the bridge wire. Vary the known resistance until a change of one ohm reverses the current through the galvanometer. Now move the slider until the galvanometer shows no deflection. Why is it best to keep the point D near the middle of the slide wire in obtaining readings? Repeat for the unknown resistance X_2. Connect the two in series and find their resistance. Repeat for the two in parallel. How do these values agree with the calculated values ? Tabulate all your results.

Part 3

Note the lengths and diameters of the samples furnished and calculate the resistance per circular-mil-foot (specific resistance). The mil is .001 inch and the circular mil is the area of a circle one mil in diameter. The resistance of a conductor is

$$R = \frac{K\ell}{d^2} \text{ or } R = \frac{\rho L}{A},$$

K = specific resistance (ohms cir. mil per ft.), ℓ = length in feet, d= diameter in mils, and R = resistance in ohms, or ρ = specific resistance (ohms cm.), L= length in cm., and A = area of cross-section in sq.cm.

Name: __________ Instructor: __________ Division: ______ Date. ______

Observations, Drawings, Computations:

Answers and Conclusions:

TEST EXPERIMENT 21

1. Three resistances of a....b....and c....ohms respectively are connected in parallel. The effective resistance of the combination (in ohms) is , (2) , (3) , (4) .... ( )

2. Two resistances in series have a combined resistance of a.... ohms and in parallel a combined resistance of b....ohms. The value of the smaller resistance (in ohms) is (1) , (2) , (3) , (4) .... ( )

3. A meter length Wheatstone bridge is set up with the scale running from left to right. A standard resistance of a....ohms is placed on the left side. A balance point of b....cm. is obtained. The resistance of the unknown (in ohms) is (1) , (2) , (3) , (4) .... ( )

4. In the Wheatstone bridge of problem (3) a known resistance of a....ohms is placed on the left and another known resistance of b....ohms on the right. The balance point (in cm.) should be (1) , (2) , (3) , (4) .... ( )

5. In the Wheatstone bridge of problem (3) a standard resistance of a....ohms is placed on the left and an unknown resistance on the right. A balance point of b....cm. is obtained. The unknown resistance is increased by c....ohms. The balance point (in cm.) will now be (1) , (2) , (3) , (4) .... ( )

6. In the Wheatstone bridge of problem (3) a known resistance of a....ohms is placed on the left and resistances of b....ohms and c....ohms connected in series on the right. The balance point (in cm.) will be (1) , (2) , (3) , (4) ,..... ( )

7. In problem (6) if the two resistances on the right are connected in parallel, the balance point (in cm.) will be (1) , (2) , (3) , (4) .... ( )

8. Three resistances of a....,b...., and c....ohms respectively are connected in parallel. The current flowing through the b.... ohm resistance is d....amp. Then the current (in amp.) flowing through the c....ohm resistance is (1) , (2) , (3) , (4) .... ( )

9. Two resistances of a.... and b....ohms respectively are connected in parallel. The potential drop across the b....ohm resistance is c....volts. The potential drop across the a....ohm resistance is (in volts) (1) , (2) , (3) , (4) .. ( )

10. Two resistances of a.... and b....ohms respectively are connected in parallel. A current of c....amp. flows in the main circuit. The current flowing through the b....ohm resistance is (in amp.) (1) , (2) , (3) , (4) .... ( )

Name: ____________ Instructor: ____________ Division: ________ Date. ________

Observations, Drawings, Computations: ____________

Answers and Conclusions: ____________

Experiment 22

THE SENSITIVE MOVING COIL GALVANOMETER

Object:

To study the sensitive galvanometer and its use as an electrical measuring instrument.

Apparatus:

Sensitive galvanometer, resistance box 1000 to 10,000 ohms range, resistance box 1 to 1000 ohms range, dry cell, switch, connections.

Theory:

A very sensitive galvanometer is one in which the moving coil is light and has a great many turns of fine wire. Necessarily the resistance is rather large and large currents can-not go through the moving coil without burning it out. These galvanometers are used for two purposes, namely, to indicate or measure electric current and to indicate or measure electric potential. The permanent magnet type as indicated in figure 1 has its deflection directly proportional to the current in the coil. It is only necessary to calibrate the scale to read any unit of current desired such as microamperes, milliamperes, amperes, etc. When large currents are to be measured, shunt resistances are connected so that some multiple of the galvanometer current goes through the shunt. Let I_g be the galvanometer current and I_s the shunt current.

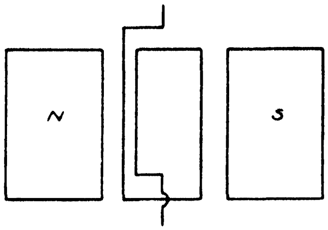


Figure 1

By Ohm's Law the drop in potential across the galvanometer coil is $I_g r_g$ and across the shunt resistance is $I_s r_s$. Since the ends a and b are common to both branches of the divided circuit in Fig. 3.,

$$V_{ab} = I_g r_g = I_s r_s .$$

Also the line current $I = I_g + I_s$.

If a galvanometer is calibrated to read microamperes it is called a microammeter; if it reads milliamperes it is called a milliameter; if it reads amperes it is called an ammeter.

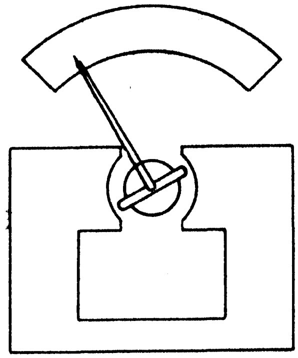


Figure 2

The galvanometer coil can not stand to have a large e.m.f. connected across it, so it is necessary to connect a series resistance M to the coil to reduce the current. The total resistance is $R = r_g + M$, and the total drop in potential across the total resistance is $V_{ac} = I_g(r_g + M)$ (see Figure 4). The instrument is calibrated to read this drop in potential. If the scale is calibrated in microvolts, the instrument is called a microvoltmeter; if it is calibrated in millivolts the instrument is called a millivoltmeter; and if it is calibrated in volts it is called a voltmeter.

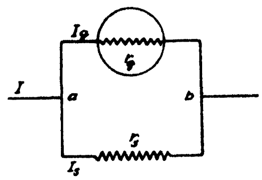


Figure 3

Experiment

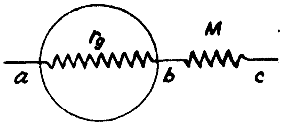
Part I

The Shunted Galvanometer.--Connect the galvanometer in series with a high resistance, a switch and a dry cell. Do not close the switch until an instructor O.K.'s the job. Find the resistance which gives a large initial scale deflection on the galvanometer and record this value. Do not change the resistance throughout this part of the experiment. Connect another resistance box across the galvanometer as a shunt. Take readings of shunt resistance and deflection with a shunt which makes the galvanometer reduce its deflection to half of its initial value. If the series resistance is very high compared to the galvanometer resistance, the current through the resistance

Name: Instructor: Division: Date.

Observations, Drawings, Computations:

Answers and Conclusions:



will remain nearly constant throughout the preceding operations. Since $I_g r_g = I_s r_s$ and $I = I_g + I_s$ = constant,

Figure 4

$$r_g = \frac{I_s}{I_g} r_s$$

$r_g = r_s$ when $I_g = I_s$.

In that case,

$$I_g + I_s = 2I_g = I \quad ,$$

and

$$I_g = (1/2) I ,$$

the total current for maximum deflection. Therefore, the galvanometer resistance is found by noting the shunt resistance corresponding to half of the deflection for no shunt. Record this resistance of the galvanometer.

With the galvanometer resistance known and the e.m.f. of the cell equal to 1.5 volts, calculate the galvanometer current at the time when the shunt was not connected and the large series resistance was in the circuit.

$$I_g = \frac{1.5}{r_g + M} .$$

From this find the galvanometer current for a deflection of one scale division.

With the galvanometer current required to produce unit scale deflection and the resistance of the galvanometer, calculate the value of a shunt resistance required to make the galvanometer into a milliameter (reading one milliampere per unit scale division).

Part 2

The Potential Meter or Voltmeter.--As stated before, the galvanometer resistance times the galvanometer current is equal to the drop in potential across the galvanometer.

$$V_{ab} = I_g r_g \quad .$$

If a resistance M is connected in series with the galvanometer, the potential difference is

$$V_{ac} = I_g (r_g + M) \quad .$$

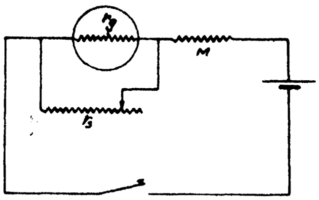


Figure 5

Calculate what series resistance M is required to give a difference in potential of one volt to produce a deflection of one unit on the galvanometer scale. Connect this resistance to the galvanometer and have the Instructor test it on two dry cells. Such an instrument is called a voltmeter.

Calculate what series resistance is required to give one-tenth volt difference in potential across galvanometer and resistance for a unit scale deflection and make a diagram of the connection showing how the galvanometer would be connected so as to have both scales ready for use as a double scale voltmeter.

Part 3

To measure the resistance of a galvanometer by a Wheatstone Bridge, see Figure 2 of Experiment 21. Connect this galvanometer in the circuit as the unknown resistance R_1 . Place in series with the dry cell a high resistance R such that the current flowing in this galvanometer will not produce a maximum scale deflection. (The allowed current and resistance to be used depend upon the type of galvanometer). Consult the Instructor before closing any switch.

Find the balance point on the slide wire and from it and the known resistance calculate the galvanometer resistance. Should this value be more accurate than that of Part I ?

Name: Instructor: Division: Date.

Observations, Drawings, Computations:

Answers and Conclusions:

TEST EXPERIMENT 22

1. With a shunt of a....ohms a certain galvanometer gives a deflection of b....divisions for a current of c....amperes. With a shunt of d....ohms the same current produces a deflection of e....divisions. The resistance of the galvanometer (in ohms) is (1) , (2) , (3) , (4) .... ( )

2. A galvanometer in series with a resistance of a....ohms gives a deflection of b....divisions for c....volts. The deflection is d....divisions for e....amperes. The resistance of the galvanometer (in ohms) is (1) , (2) , (3) , (4) .... ( )

3. A galvanometer of a....ohms resistance is deflected b....divisions by a current of c....amperes. When connected across a d.... volt drop, the deflection is (1) , (2) , (3) , (4) .( )

4. In order to have the galvanometer of problem (3) indicate a.... divisions per volt, it requires a series resistance (in ohms) of (1) , (2) , (3) , (4) .... ( )

5. In order to have the galvanometer of problem (3) indicate a.... divisions per ampere, it requires a shunt resistance (in ohms) of about (1) , (2) , (3) , (4) .... ( )

6. A galvanometer of a....ohms resistance is deflected b....divisions (full scale) by a current of c....amp. Hence the value of the series resistance that must be used with the instrument in order that full scale deflection would correspond to d....volts is (in ohms) (1) , (2) , (3) , (4) .... ( )

7. A galvanometer of a....ohms resistance is deflected b....divisions when c....volts is applied across its terminals. Upon introducing a resistor in series, the deflection was observed to be d....divisions. Hence the value of the resistor (in ohms) must have been (1) , (2) , (3) , (4) .... ( )

8. With the apparatus used in the half-deflection method, a galvanometer of a....ohms resistance reads b....divisions without the shunt. When shunted, the deflection is c....divisions. The resistance of the shunt (in ohms) is (1) , (2) , (3) , (4) .... ( )

9. A galvanometer of a....ohms resistance is deflected b....divisions (full scale) by a current of c....amp. Hence the value of the shunt that must be used with this instrument in order that full scale deflection would correspond to d....amp. is (in ohms) (1) , (2) , (3) , (4) .... ( )

10. The current flowing through a circuit consisting a galvanometer of a....ohms resistance shunted by a resistor of b....ohms resistance is c....amp. Hence the current through the galvanometer is (in amp.)(1) , (2) , (3) , (4) .... ( )

Name: ______________ Instructor: ______________ Division: ________ Date. ________

Observations, Drawings, Computations: ______________

Answers and Conclusions: ______________

Experiment 23

THE ELECTROLYTIC CELL

Object:

The study of Faraday's Laws of Electrolysis.

Apparatus:

Hydrogen and copper electrolytic cells, ammeter, rheostat, switch, battery, alcohol, fine sandpaper, beam balance and weights.

Theory:

The voltameter is simply an electrolytic cell designed for measuring the amount of substance deposited by a quantity of electricity.

Faraday's laws of electrolysis are embodied in the equation

$$m = \mathcal{Z} It = \mathcal{Z} Q, \qquad (1)$$

where m = mass of substance deposited in grams,
$\mathcal{Z}$ = electrochemical equivalent, i.e., grams/coulombs,
Q = quantity of electricity in coulombs,
I = current in amperes,
t = time of current flow in seconds.

The electrochemical equivalent is defined as follows:

$$\mathcal{Z} = \frac{W}{96500\ z}, \qquad (2)$$

where w = atomic weight in grams,
z = valence

When the products of the electrolytic action are gaseous, the amounts deposited are most conveniently determined by measuring the volumes of the gases.

The relation between volume and mass is $m = dV$. For gases the density d and the volume V are usually referred to standard conditions of 0°C. and a pressure of 76 cm. of mercury. Thus it is more definite to write the preceding equation as

$$m = d_s V_s \ .$$

With this change Faraday's Law becomes

$$V_s = \frac{\mathcal{Z} It}{d_s}. \qquad (3)$$

The volumes of the gases collected depend on their temperatures and pressures. The gas law is $pV = RT$. Therefore

$$\frac{pV}{p_s V_s} = \frac{RT}{RT_s} = \frac{T}{T_s}$$

whence

$$V_s = \frac{pT_s}{p_s T} V \ . \qquad (4)$$

Pressure may be expressed in terms of the height of a column of mercury by the relation $p = d\,gh$, and making this substitution in equation (4) gives

$$V_s = \frac{hT_s}{h_s T} V \ . \qquad (5)$$

(Remember that T is absolute temperature.)

The pressure denoted by h in equation (5) consists of 3 parts, the air pressure h_A, the hydraulic pressure h_H, and the vapor pressure h_v of the water vapor intermixed with the collected gases:

$$h = h_A + h_H - h_v \ .$$

h_H will be given in cm. of mercury if the difference in water levels in cm. is divided by 13.6. The vapor pressures of water are:

T (°C)	h_v (cm. of mercury)
20°	1.74
21°	1.85
22°	1.96
23°	2.09
24°	2.22
25°	2.35
26°	2.50
27°	2.65
28°	2.81
29°	2.97
30°	3.15

The other necessary data are:

	At. wt.	Valence	Density (d_s)
Copper	63.57	2	8.9 gm./cc.
Hydrogen	1.008	1	$.09 \times 10^{-3}$
Oxygen	16.	2	1.43×10^{-3}

By Avogadro's Law there is an equal number of atoms in every gram-atom N, so the atomic weight might be written

$$W = Nm_a \ , \qquad (6)$$

where m_a = mass of one atom and numerically $N = 6.06 \times 10^{23}$.

Combining equations (1) and (2) gives

$$m = \frac{QW}{96500\ z} \qquad (7)$$

Name: Instructor: Division: Date.

Observations, Drawings, Computations:

Answers and Conclusions:

and substituting equation (6) in this, one gets

$$m = \frac{NQm_a}{96500\ z}\ . \qquad (8)$$

Suppose the mass deposited is just one atom, that is, only one ion has been neutralized by a charge Q_1 ; then $m = m_a$ and the ionic charge is by equation (8),

$$Q_i^{\bullet} = \frac{96500\ z}{N}\ . \qquad (9)$$

Since the quantities 96500 and N are universal constants, the only variable on the right is z, and thus the smallest possible ionic charge in electrolysis is obtained when $z = 1$. This was found to be the charge of an electron. So

$$e = \frac{96500}{6.06 \times 10^{23}} = 1.59 \times 10^{-19} \text{ coulombs.}$$

Combining equations (7) and (9) gives for $Q_i^{\bullet}$

$$Q_i^{\bullet} = \frac{wQ}{Nm}\ . \qquad (10)$$

From this equation it is possible to determine the charge of an ion by the measurements to be carried out in this experiment.

Experiment

Part 1

Electrolysis of Acidulated Water.--Connect the ammeter A, voltameter V, rheostat R, switch S and batteries B in series as shown in the diagram. Pass a current of about 1/4 to 1/2 ampere until sufficient gas has been collected to be accurately measured.

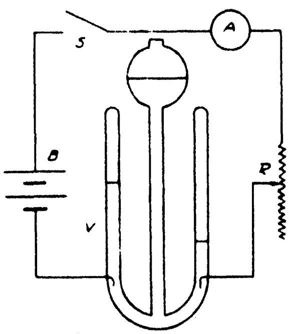


Figure 1

Record the volumes obtained and reduce these to standard conditions and record results.

Having recorded the current every 1/2 minute and the total time it was allowed to flow, calculate the volumes that should have been obtained according to Faraday's Law.

Note: Keep the value of the current constant by adjusting the rheostat.

Find the percent of error between the experimental and theoretical volumes obtained.

Best results for experimental volumes will be obtained if the apparatus is given a trial run to saturate the electrolyte with gases that will dissolve.

Part 2

Copper Electroplating.--Replace the water electrolysis apparatus by the copper voltameter. Clean and weigh the cathode before placing it in the voltameter. Be sure the polarity of the voltameter is correct.

Close the switch and pass a steady current for a measured time. To get a firm deposit of copper the current density, in respect to the cathode, should not be much greater than .02 amp. per sq. cm. Read the ammeter every 1/2 minute and by means of the rheostat keep the current steady.

After depositing about 1/2 gm. of copper (the time required to do this should be calculated beforehand), open the switch, remove the cathode, rinse in a gentle current of water, then in alcohol, dry on clean blotting paper and weigh carefully. Exercise care not to scrape off any of the copper granules.

Record in a table the original weight of the cathode, the weight after deposit, the mass of the copper deposited, the mass calculated to be deposited, the current and the time it was allowed to flow.

Find the per cent of error between the theoretical and experimental masses obtained.

Part 3

Calculate the theoretical charge in coulombs on the hydrogen, oxygen and copper ions.

Using the experimental values of masses obtained, calculate the charge on each of the above ions.

Compare the results by recording them in adjacent columns of a table.

Name:______________________ Instructor:______________________ Division:__________ Date.__________

Observations, Drawings, Computations:

Answers and Conclusions:

TEST EXPERIMENT 23

1. The electrochemical equivalent of silver (atomic mass 108, valence 1) is 0.001118 gm. per coulomb. Hence the electrochemical equivalent of another element (atomic mass a....., valence b....) is (in gm. per coulomb) (1) , (2) , (3) , (4) . . . . ( )

2. Element A (atomic wt. a....valence b....) and element B (atomic wt. c....., valence d....) are deposited on plates in two cells which are in series with a source of e.m.f. The relative weights deposited are in the ratio (1) , (2) , (3) , (4) . . ( )

3. The ratio of the quantity of electricity necessary to deposit a....gm. of aluminum to that required to deposit b....gm. of iron (atomic wts. Al-27, Fe-56, valences Al-3, Fe-2) is (1) , (2) , (3) , (4) . . . . ( )

4. A current of a....amp. for b....minutes will deposit a mass of silver (in gm.) of (1) , (2) , (3) , (4) . . . . ( )

5. Experimentally it is found that a....coulombs of electricity are required to deposit b....gm. of an element (atomic wt. c....., valence d....). This data gives for the charge on the electron (in coulombs) (1) , (2) , (3) , (4) . . . . ( )

6. The number of NaCl molecules (atomic wts:Na-23, Cl-35.5) in a.....gm. of common salt (dehydrated) is (1) , (2) , (3) , (4) . . . . ( )

7. A coulomb of electricity will deposit a mass (in gm.) of an element (atomic wt. a....valence b....) of about (1) , (2) , (3) , (4) . . . . ( )

8. One gram-atom of an element (atomic wt. a...., valence b....) is deposited by (1) , (2) , (3) , (4) coulombs. . ( )

9. Two electrolytic cells are connected in series and a definite quantity of electricity is sent through them. If the first cell deposits a mass m_1 of one element (atomic wt. a...., valence b....) and the second a mass m_2 of another element (atomic wt. c...., valence d....), then the ratio m/m_2 is (1) , (2) , (3) , (4) . . . . ( )

10. A current flows through a copper salt solution for a....sec. and deposits b....gm. of copper (atomic wt. 63.57, valence 2). The current (in amp.) is (1) , (2) , (3) , (4) . . . . ( )

Avagadro's N = 6.06×10^{23} atoms per gram. atom.

Name: ________________ Instructor: ________________ Division: ________ Date. ________

Observations, Drawings, Computations:

Answers and Conclusions:

Experiment 24

THE POTENTIOMETER AND THE THERMOCOUPLE

Object:

To study the principle of the potentiometer and use it to measure the e.m.f.'s of thermocouples.

Apparatus:

Potentiometer of the stretched wire type, 10-10000 ohm resistance box, rheostat, 3 dry cells, standard cell, reversing switch, series of thermoelectric couples called a thermopile, 100° thermometer, two calorimeter cups, ice and hot water.

Theory:

The potentiometer is, as its name implies, a potential meter. The potential is measured by comparing it with a known standard potential, namely, that of a standard cell. The comparison is made by a null method which requires no current to flow in the source of e.m.f. being tested. This is accomplished by balancing along a stretched wire resistance an opposing e.m.f. A diagram of the circuit is given (see Figure 1) to show how to make the connections.

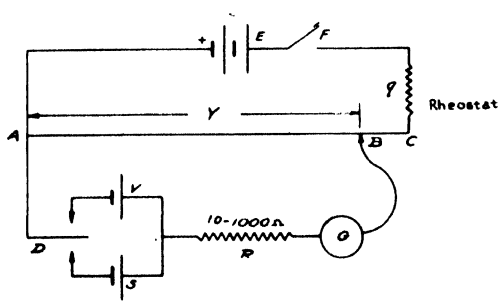


Figure 1

Ohm's Law states that the difference in potential along a conductor carrying a current is equal to the current times the resistance of the conductor. Due to the cell E, the circuit EABC has a current I flowing in it. If the resistance between A and B is r, the drop in potential from A to B is $V_{ab} = Ir$ by Ohm's law. If the cells E and S are connected in opposition and the point B is adjusted so that the potential difference V_{ab} is equal and opposite to the e.m.f. of the standard cell S, no current will flow through the cell S and the sensitive galvanometer G will not be affected. If the conductor AB is of uniform resistance K ohms per unit length, the distance Y from A to B is proportional to V_{ab} since $V_{ab} = IKY$.

In order to compare the e.m.f.'s of two cells S and V, it is only necessary to compare the two corresponding lengths Y_s and Y_v of the stretched wire as measured when the current through the galvanometer G is zero. Thus

$$E_v/E_s = Y_v/Y_s \quad , \qquad (1)$$

and

$$E_v = E_s \frac{Y_v}{Y_s} .$$

The e.m.f. of the standard cell is marked on the cell and is about 1.0183 volts at 20°C.

If some other source of e.m.f. is connected in the place of the cell V, its e.m.f. can be measured in a similar way.

If two kinds of metal wires such as copper and iron are joined together, an end of one to an end of the other, a difference in potential will exist between the wires at the contact point which will depend upon the temperature of the junction. If the other two ends are joined together at the same temperature, no current will flow in the completed circuit because the e.m.f.'s set up at each junction are in opposite direction and equal in magnitude. If one junction is heated to a higher temperature than the other, the e.m.f. of one junction will be greater than that of the other, and a current will flow in the circuit.

This phenomenon is known as the thermoelectric effect and the two junctions are called a thermocouple. A number of junctions connected in series is called a thermopile.

Experiment

Part I

Connect the stretched wire potentiometer, 10-10000 ohm resistance box, dry cell, standard cell, galvanometer, rheostat and switches as in Figure 1. Do not close the switches until the connections are checked by the Instructor.

Close the switches F and D so that the dry cells V and E are connected. Then adjust the sliding contact point B so that Y_v is 150 cm. Adjust the resistance q so that the galvanometer reads zero when contact B is pressed down. One centimeter of wire now has a potential difference of approximately 1/100 volt, since the e.m.f. of the cell V is about 1.50 volts. To make the calibration more accurate, reverse the switch D so that the standard cell S is connected instead of V, and set B so that Y_s equals

Name: ______________________ Instructor: ______________________ Division: __________ Date. __________

Observations, Drawings, Computations: ______________________

Answers and Conclusions: ______________________

100 times the e.m.f. of the standard cell. Then adjust the resistance q so that the galvanometer reads zero when contact is made at B. Then the potential drop along the wire is 1/100 volt per cm. To make the instrument more sensitive, remove the resistor R after the calibration has been made. This resistor is only a device for protecting the galvanometer and standard cell from excessive currents. Leave the resistance q fixed for the rest of the experiment.

Throw the switch D over to connect the cell V in the circuit. Adjust the contact B so that the galvanometer indicates zero current when it is pressed down. Read the e.m.f. of the cell V directly from Y_V.

Part 2

In this part the e.m.f. of a thermopile will be measured by connecting the thermopile in the circuit (Figure 1) in place of the cell V. Place the thermopile so that the two ends dip into two cups of water. With the water in the two cups at the same temperature (room temperatire), find the e.m.f. produced in the thermopile. It should be zero; that is, the point B should coincide with A when the galvanometer shows no deflection.

Pour the water out of one cup (into which the "cold" end is placed) and replace it with shaved ice. Bring the water in the other cup to the boiling point. After about 10 minutes find the balancing point B along the wire and from that the e.m.f. of the thermopile.

By dividing the e.m.f. of the thermopile (reduced to microvolts) by the number of couples, find the e.m.f. per couple. Then divide this result by the temperature difference between the two sets of junctions to find the thermoelectric power of the couple in microvolts per degree.

Tabulate all of the results.

Name: ______________________ Instructor: ______________________ Division: __________ Date. __________

Observations, Drawings, Computations:

Answers and Conclusions:

Experiment

Part I

Describe the induction coil used and make a diagram of the whole circuit.

What are the factors which increase the e.m.f. in the secondary circuit?

Why is a condenser used across the break gap in the primary circuit?

What are the differences between a transformer and an induction coil?

Part 2

The earth inductor consists of a coil of wire wound around a wooden frame which rotates about a vertical axis at an angular speed ω rad./sec. (A commutator and two brushes are a part of the inductor). The horizontal component of the earth's magnetic field is directed toward the magnetic north. A sensitive D.C. Galvanometer is connected to the brushes to indicate the mean value of the current.

In some instruments the brushes are on a yoke which can be rotated around carrying the brushes with it; shifting the position of the brushes changes the amount of rectification produced by the commutator and thereby changes the reading of the galvanometer. A position of the brushes can be found whereby no rectification is accomplished and there will be no reading of the galvanometer.

Rotate the yoke until a position is found which gives maximum current as indicated by the galvanometer. The number of revolutions per second must be measured with a revolution counter and stop watch. The resistance of the circuit, constant of the galvanometer, and number of turns can be obtained from the Instructor.

Calculate the horizontal component of the earth's magnetic field. (Use the constant of the galvanometer to find E, the mean e.m.f. induced in volts).

Part 3

Study apparatus. Give detailed description of how an earth inductor could be used as a compass.

Name: ______________ Instructor: ______________ Division: ________ Date. ______

Observations, Drawings, Computations: ______________

Answers and Conclusions: ______________

1. The coefficient of mutual induction between two coils is a... henries. If the rate of change of current in one of them is b....amp./sec., the e.m.f. (in volts) induced in the other is (1) , (2) , (3) , (4) . . . . (

2. A coil of a....turns and b....sq.cm. in area is rotated c.... deg. about an axis perpendicular to a magnetic field of d.... oersteds in e....seconds. The average induced e.m.f. (in volts) is (1) , (2) , (3) , (4) . . . . (

3. The axis of a coil of a....turns and an area of b....sq. cm. is inclined at an angle of c....deg. to a magnetic field of d.... oersteds. The average e.m.f. (in volts) induced when it is rotated at e....R.P.M. is (1) , (2) , (3) , (4) . (

4. A long straight wire conductor a....cm. long passes through a magnetic field of b....lines/sq.cm. at the rate of c....cm./sec. The e.m.f. (in volts) between its ends is (1) , (2) , (3) , (4) . . . . (

5. A coil rotates in a uniform field of a....oersteds; it contains b....turns of wire; has an area of c....sq.cm. and an angular velocity of d....radians/sec. Then the average e.m.f. (in volts) induced in a quarter of a revolution (starting with its plane parallel to the direction of the lines of force) is (1) , (2) , (3) , (4) . . . . (

6. A coil of a....turns and b....sq.cm. in area is rotated one complete revolution about an axis perpendicular to a field of c....oersteds in d....sec. The average induced e.m.f. (in volts) is (1) , (2) , (3) , (4) . . . . (

7. The coefficient of mutual induction between two coils is a.... henries. An e.m.f. of b....volts is induced in one coil when the current in the other coil changes at the rate (in amps. per sec.) of (1) , (2) , (3) , (4) . . . . (

8. It is observed that when a conductor is connected to an external resistance, a....coulombs of electricity will flow if b.... joules of energy are expended upon it in moving it through a distance of c....cm. Hence the e.m.f. induced (in volts) is (1) , (2) , (3) , (4) . . . . (

9. If the conductor of problem (8) is connected to an external resistor of a....ohms and cuts b...lines of force in c....seconds, then the average current (in amp.) flowing through the resistor is (1) , (2) , (3) , (4) . . . . (

10. It is observed that when the current in one of two coils is increased from a....to b....amp. in c....seconds, that an e.m.f. of d....volts is induced in the other. Hence the mutual inductance (in henries) is (1) , (2) , (3) , (4) . . (

Name: ____________ Instructor: ____________ Division: ______ Date. ______

Observations, Drawings, Computations:

Answers and Conclusions:

Experiment 26

VELOCITY OF SOUND IN METALS

Object :

To compare the velocity of sound in several metals with the velocity in air by means of Kundt's tube.

Apparatus:

Kundt's tube, metal rods, cloth, resin.

Figure I

Theory:

Kundt's dust figure apparatus as shown in the figure consists of the sounding rod A, clamped at the center and carrying a disk at one end. This disk is placed in the wave tube B so that it does not touch the tube. The opposite end of B is closed by a close fitting piston. Some fine dry powder, such as lycopodium, cork dust, powdered elder pith, or cornstalk pith is strewn along the bottom of the tube. The free end of A is rubbed longitudinally with rosined leather to set it into vibration. When the length of B between disk and piston is a adjusted to almost an integral number of half wave lengths of the sound emitted by the rod, the air is set into strong forced vibrations of the same frequency. The wave length will be twice the distance between nodes in the tube, the nodes being indicated by minimum disturbances of the dust in the tube. The wave length of the same vibration in the rod is twice the length of the rod. The equation for speed of wave motion is the same for both cases, namely

$$V = f\lambda ,$$

where V is the speed, f is frequency, λ is wave length. Since the air column is forced to vibrate at the same frequency as the rod, f is the same for both. Hence,

$$\frac{V\ rod}{V\ air} = \frac{\lambda rod}{\lambda air} .$$

Experiment

Part I

Clean the wave tube, if necessary, by pushing a wad of cotton or waste through it. Place enough of the powder in the tube to form a line about 2 mm. wide along the bottom of the tube when placed horizontally on the V-Blocks. See that the disk on the end of the rod is two or three cm. within the tube and not in contact with it at any point. Tap the tube lightly so that the dust will form a line along the bottom, then rotate the tube until the powder is about to slide down the wall of the tube. See that the piston is close to the opposite end of the tube from the disk, then stroke the free end of the rod lengthwise with rosined leather. It should emit a shrill sound. If the tube is of proper length, the powder will remain at rest at a few definite points and will move down toward the bottom of the tube between these points. If the points of rest are not distinct, move the piston slightly and stroke the rod again. Continue adjusting the piston until the most definite nodal points are found. Measure the length of rod and the distance between nodal points. Use these measurements to determine the speed of sound in the particular rod used. Since the disc is not exactly at a node, do not measure from it to the piston.

Part 2

Repeat the above work, replacing the rod in succession by other rods furnished, and determine the speed of sound in each.

Part 3

For longitudinal vibrations of a solid the speed of wave motion is given by

$$V = \sqrt{\frac{E}{d}} ,$$

where E is Young's Modulus and d is the density. From the velocity found in part 2 calculate Young's Modulus for one or more of the materials used, as directed by your Instructor.

Density (in gm. per cc.) of Brass = 8.5; Aluminum = 2.6; Steel = 7.5.

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Observations, Drawings, Computations:

Answers and Conclusions:

TEST EXPERIMENT 26

1. A metal rod a....cm. long clamped in the middle causes standing waves inside a glass tube. When the fundamental note of the rod is produced, the nodes in the tube are b...cm. apart. Taking the velocity of sound in air as 330 m./sec., the frequency of the sound emitted (in vib. per sec.) is (1) , (2) , (3) , (4) . . . . (

2. If the velocity of sound in air is 330 m./sec., the velocity of sound in the metal rod of problem (1) is (in m./ sec.) (1) , (2) , (3) , (4) . . . . (

3. The nodes for carbon dioxide (velocity of sound 258m./sec.) in the tube of problem (1) would have a separation (in cm.) of (1) , (2) , (3) , (4) . . . . (

4. The next frequency produced by the rod of problem (1) would produce nodes (air in the tube) which are separated by a distance (in cm.) of (1) , (2) , (3) , (4) . . . . (

5. The air in a closed organ pipe a....cm. long is set into vibration. The frequency of the third harmonic (in vib. per sec.) is (1) , (2) , (3) , (4) . . . . (

6. To cause an open organ pipe to emit notes of a fundamental frequency of a....vib./sec., one would make its length (in cm.) equal to (1) , (2) , (3) , (4) . . . . (

7. If the density of a certain metal is a....gm./cc., and the velocity of sound in it is b....m./sec., Young's modulus for the metal (in dynes per sq. cm.) is (1) , (2) , (3) , (4) . (

8. In a Kundt's tube experiment it was found that the distance between successive nodes was a....cm. The frequency of the sound (in vib./ sec.) was therefore (1) , (2) , (3) , (4) . (

9. When a different metal bar was used, the distance between the first and sixth antinode was found to be a....cm. In this case the frequency (in vib./ sec.) was (1) , (2) , (3) , (4) . (

10. The frequency of the fundamental note of a bar clamped at the center is a....vib./sec. If clamped one quarter of the length from one end, the fundamental frequency (in vib./ sec.) is (1) , (2) , (3) , (4) . . . . (

Name: Instructor: Division: Date.

Observations, Drawings, Computations:

Answers and Conclusions:

Experiment 27

FORMATION OF IMAGES BY LIGHT FROM SPHERICAL MIRRORS

Object:

To apply the simple laws of reflection of light from plane surfaces to the study of the images formed by light from curved surfaces.

Apparatus:

Concave mirror, spherometer, protractor, compass and pins.

Theory:

The laws of reflection are:

1. The incident ray, the reflected ray, and the normal to the surface at the point of incidence all lie in one plane.

2. The angle of incidence (angle between incident ray and normal) equals the angle of reflection (angle between reflected ray and normal).

These laws apply equally well in cases where the surface on which the light is incident is not plane. In the case of a curved surface the direction of the normal changes from place to place on the surface, but at each point it is nevertheless true that a ray incident at that point is reflected at that point in accordance with the above two laws.

In the case of a spherical surface, the normals to points on the surface are simply the radii of the sphere. The drawing of ray diagrams is therefore simplified by that fact.

For a spherical mirror the distance from the object to the mirror (object distance p), the distance from the mirror to the image (image distance q), and the focal length f are related by:

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f} = \frac{2}{r}. \tag{1}$$

The last equality follows from the fact that the focal length f is one-half of r, the radius of curvature of the spherical mirror.

Experiment

Part I

First, determine the curvature of the mirror by means of a spherometer. Place the instrument on a flat piece of plate glass and adjust the central screw until all four legs touch the plane surface. Read and record the positions of the various scales. Measure the distance from each outside leg to the one in the center. Place the spherometer on the mirror and again adjust the central screw until all the legs are touching. Caution: To avoid errors due to faulty scale marks, count the revolutions as they are made in the new adjustment.

Referring to Figure I, it follows from Pythagoras' theorem that

$$\overline{AC}^2 = \overline{AB}^2 + \overline{BC}^2$$

This may be written:

$$r^2 = y^2 + (r - S)^2$$

$$= y^2 + r^2 - 2r\,S + S^2,$$

or

$$y^2 - 2r\,S + S^2 = 0.$$

S is small compared to r and hence S^2 is neglected

$$2r = \frac{y^2}{S}. \tag{2}$$

But y is the measured distance from the central leg to any one of the outside legs, and S is measured by the central screw. Then r, the radius of curvature of the mirror, can be calculated from equation (2).

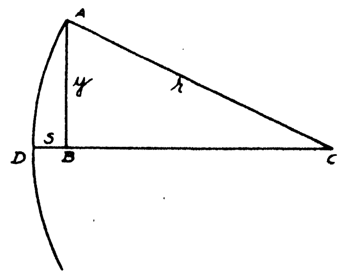

Figure I

(a) Place a small object along the axis of the mirror at a distance of about 50 cm. from the mirror. To locate the position of the image, place a pin at the point where the image appears. Now move your eye from side to side and if the image of the object continues to coincide with the pin as the eye is moved, then the pin properly marks the position of the image. This method of locating the image is called the method of parallax. Now measure the image distance and compare it with the calculated value obtained by substituting in equation (1).

Is the image real or virtual, erect or inverted, magnified or reduced? (The magnification is equal to $\frac{q}{p}$.)

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Observations, Drawings, Computations:

Answers and Conclusions:

(b) Repeat the experiment placing the object at a distance of about $\frac{3}{4}$ r from the mirror.

(c) Repeat again with object at about $\frac{3}{8}$ r from the mirror.

Part 2

Draw a ray diagram to scale for each of the above cases. Draw a ray diagram and describe the image that would be obtained for the case of an object 2 cm. high placed 5 cm. in front of a convex mirror of 12 cm. radius of curvature.

Galvanometer mirrors are usually made concave and a beam of light from a lamp is incident on the mirror, and the image of the lamp is then focused on a scale. If the galvanometer mirror rotates through an angle θ, what is the angle between the incident and reflected beam?

Part 3

By aid of a ray diagram prove that for spherical mirrors (use a concave mirror):

$$f = \frac{r}{2} \quad .$$

(Use rays near the axis and parallel to it.)

Show by an accurate drawing that rays parallel to the axis which are near the axis have a longer focus than those which are farther from the axis. This fact is called "spherical aberration", and implies that when a plane wave is incident on a spherical mirror, it is not reflected in the form of a true spherical wave.

Name: ________________ Instructor: ________________ Division: ________ Date. ________

Observations, Drawings, Computations:

Answers and Conclusions:

TEST EXPERIMENT 27

1. If the incident ray from an object placed in front of a plane mirror is observed to be at an angle of a....deg. with the mirror, then a line joining the image and object makes an angle (in degrees) with the mirror of (1) , (2) , (3) , (4) . . . (

2. Two plane mirrors are hinged at one edge which is vertical and the angle between the reflecting surfaces is a....deg. If a horizontal ray of light is incident on one at an angle of b....deg. with the normal, the ray reflected from the other will make an angle with its normal of (1) , (2) , (3) , (4) . (

3. A spherical mirror focuses the image of an infinitely distant object at a point a....cm. distant from the mirror surface on its principal axis. The radius of curvature of the mirror is (in cm.) (1) , (2) , (3) , (4) . . . . (

4. The distance of an object from a spherical mirror (radius of curvature a....cm.) is b....cm. The distance of the image formed from the mirror is (in cm.) (1) , (2) , (3) , (4) . (

5. An object is a....cm. in front of a concave mirror whose radius of curvature is b....cm. The image distance from the mirror is (in cm.) (1) , (2) , (3) , (4) . . . . (

6. An object is placed a....cm. in front of a convex mirror and an erect virtual image b....times the size of the object is formed. Thus the radius of curvature of the mirror (in cm.) is (1) , (2) , (3) , (4) . . . . (

7. A convex mirror with radius of curvature of a....cm. has an object b....cm. in front of it. The distance of the image from the mirror (in cm.) is (1) , (2) , (3) , (4) . . . (

8. If the difference between spherometer adjustments is a....mm. and the distance between center and outside legs is b....cm., then parallel light will be focused at a distance of (1) , (2) , (3) , (4) cm. from the mirror . . . . (

9. A concave mirror of focal length a....cm. is b....cm. from a convex mirror of focal length c....cm., and the mirrors face each other. If an object is placed d....cm. behind the convex mirror, the distance from the object to the final image (in cm.) is (1) , (2) , (3) , (4) . . . . (

10. An object is a....cm. in front of a concave mirror whose radius of curvature is 2a....cm. The image distance from the mirror is (in cm.) (1) , (2) , (3) , (4) . . . . (

Name: Instructor: Division: Date.

Observations, Drawings, Computations:

Answers and Conclusions:

Experiment 28

CHANGE OF WAVE FRONT ON REFRACTION

Object:

To study refraction at plane surfaces.

Apparatus:

Cube of glass, drawing board, microscope, clamp stand, straight pins, protractor, compass.

Theory:

By studying the changes in wave front which occur as a wave advances, it is possible to predict the effects that are produced when a wave encounters an obstruction or when it is reflected or refracted. Wave front constructions are carried out by application of Huygen's Principle: Every point on a wave front acts as though it were itself a center of disturbance, sending out little wavelets of its own, always away from the source, the collective effect of which for all the points constitutes a new wave front. Starting with a wave front in any given position, the wavelets may be represented by arcs drawn from various points on the wave front as centers, the radius representing the distance the wavelets would advance in some specified time. The envelope of these arcs represents the new wave front.

Huygen's Principle may be used to determine what happens to a plane wave incident upon a plane surface OA separating two isotropic media of different wave velocities; the velocity of the wave being less in the second medium than in the first (see Figure I). Let AB be the plane front of an advancing wave making an angle of incidence, i, with the normal EF. Since the velocity v_2 in the second medium is less than the velocity v_1 in the first, the part of the wave front that strikes the surface first will be retarded in velocity to v_2 while the rest continues to proceed with velocity v_1.

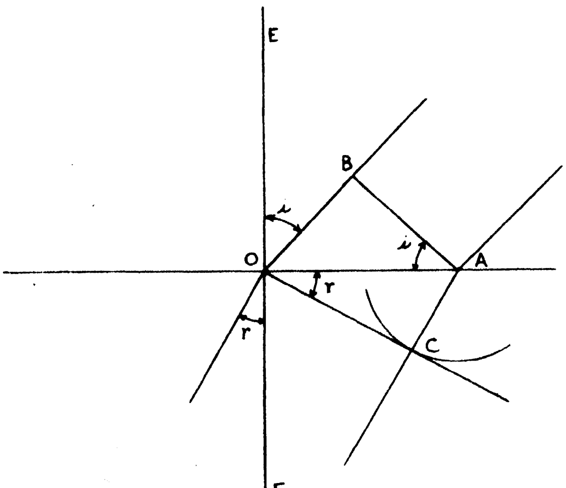

Figure I

It takes a time t for the upper part of the wave to travel from B to O with velocity v_1, and at the same time the lower part travels from A to C with velocity v_2 (OC the refracted wave front, is perpendicular to AC and so $\angle AOC = r$). r represents the angle of refraction between the refracted wave and the normal EF. The distances BO and AC are:

$$BO = v_1 t, \qquad AC = v_2 t,$$

In triangle ABO, $\angle OAB = i$ and hence

$$\sin i = \frac{BO}{AO} \text{ or } AO = \frac{V_1 t}{\sin i}.$$

In triangle AOC:

$$\sin r = \frac{AC}{AO} \text{ or } AO = \frac{V_2 t}{\sin r}.$$

By equating the two expressions for AO, one obtains

$$\text{(1)} \qquad \frac{\sin i}{\sin r} = \frac{V_1}{V_2} = \mu,$$

where μ, the index of refraction of medium 2 with respect to medium 1, is defined as the ratio of the velocity of the wave in the first medium to its velocity in the second. Equation (1) is the mathematical statement of Snell's Law. The absolute index of refraction of a medium is the ratio of the velocity in vacuum (approximately equal to that in air for light waves) to that in the given medium.

Refraction causes an object which is immersed in a medium of higher refractive index than air to appear nearer the surface than it actually is (see Figure 2). Let O represent an object in water a distance GO below the surface S. Two of the light rays extending to the eye are shown. For ray OXY, the angle of incidence = GOX and the angle of refraction = GIX; hence from eq. (1):

$$\frac{\sin GOX}{\sin GIX} = \frac{1}{\mu},$$

where μ is the refractive index of water. For rays close to the normal, angles GOX and GIX are small so that their tangents may be substituted for the sines:

$$\frac{\tan GOX}{\tan GIX} = \frac{1}{\mu}$$

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Observations, Drawings, Computations:

Answers and Conclusions:

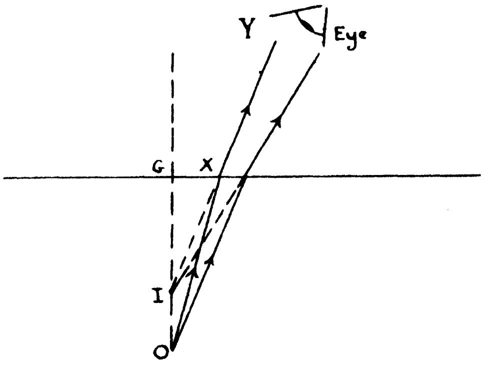

Figure 2

By reference to the figure it is seen that:

$$\frac{\tan GOX}{\tan GIX} = \frac{GX}{GO} \div \frac{GX}{GI} = \frac{GI}{GO}$$

Hence

(2) $$\frac{GO}{GI} = \frac{\text{True depth}}{\text{Apparent depth}} = \mu$$

On account of the assumption that the rays lie close to the normal, one must be careful, in the experiment, to avoid the error of examining the extreme portions of the wave front (i.e. rays making a wide angle with the normal).

Experiment

Part I

Draw an ink line on white paper placed on the drawing board, and place on it a glass cube so that the line will bisect the bottom of the cube. Place a pointer so that it touches one of the vertical faces of the cube just above the line on the paper. With the eye directly above the pointer and looking through the glass, raise and lower the pointer until it appears to be at the same level as the line. Move the eye back and forth at right angles to the line to see if there is any relative movement of pointer and line. If not, the pointer is at the apparent depth of the line as seen through the glass. Measure the distance from the bottom of the cube to the pointer. This is the apparent elevation of the line above the paper.

Repeat the operation four times. Measure the thickness of the glass block and compute the refractive index of the glass from equation (2).

Mount the microscope in the clamp stand and focus it on the line on the paper while looking through the glass cube. Measure the distance from the lower end of the microscope to the paper. Remove the cube and repeat the process by changing the elevation of the microscope above the paper. Do not change the focus. From the two measurements find the apparent thickness of the glass. Compute the refractive index. Repeat these measurements four times.

Part 2

Put the cube on the paper and draw the line LMNO around the base (see Figure 3). Look along face MN toward the point N and locate with a pencil the point P where the point N appears to be when viewed through the glass. MP is the apparent depth d. As in Part I compute the index of refraction μ. With the eye at any point, for example point I, place two pins in the paper between the cube and the eye, in line with N as it appears in the cube. Do the same for other points as shown in the figure. Now remove the cube and draw in the lines NFI, NCH, and NEG, as shown representing the actual paths of the light.

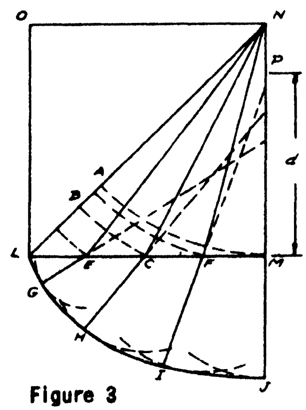

Figure 3

Now with NM as a radius and N as center, strike the arc AM which represents the spherical front of a wave advancing from N. Since the entire wave front will not leave the cube at the same instant, make a Huyghen's construction to determine what change, if any, occurs in the wave front. While the wave is traveling in glass from A to L in time t, and with velocity v_1, it is traveling outward in air along MJ with velocity v_2. To find the distance traveled in the same time t along MJ, multiply the length of AI by $\mu = v_2/v_1$ and strike an arc with M as center and $\mu \cdot$ AL as a radius. Strike also the arc BC, with NC as a radius. While the wave is traveling from B to L in glass it is traveling a greater distance in air, equal to $\mu \cdot$ BL, along the path CH.

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Observations, Drawings, Computations:

Answers and Conclusions:

With $\mu \cdot$ BL as a radius and C as center, strike an arc. Perform this same operation for the point E of the ray NE, and construct the corresponding arc. The smooth curve which is tangent to these arcs (and to all other possible arcs which might be drawn in the same manner) is the new wave front, LGHIJ. Is this a spherical front? Give sound reasons for your answer. Does the wave front have spherical aberration?

How might the front face of the cube be altered so that for a point source of light at a corner, N, of the cube, the emergent wave would be perfectly spherical, and hence free from spherical aberration?

Now, to check the accuracy of your observation in Part 2, repeat enough of the experiment (new drawing) to obtain the ray NCH, as shown in Figure 3a. Erect a normal to LM at C. Measure as accurately as possible the angles i and r as indicated.

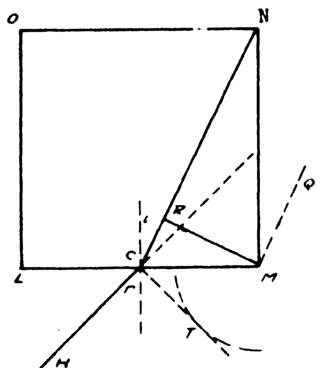

Figure 3a

Obtain from a table the sines of these angles. Since one wishes to compute the refractive index of glass with respect to air when the light is traveling from glass to air, Snell's Law is written in the form:

$$\frac{1}{\mu} = \frac{\sin i}{\sin r} \quad .$$

With your values of sin i and sin r find a value of μ. Compare this value with that found in the first part of Part I.

Now, to further verify this value of μ by means of a Huyghen's construction, draw QM parallel to NC, and RM perpendicular to NC, so that RM may be regarded as the plane front of an advancing wave. With $\mu \cdot$ RC as a radius and M as center, strike an arc. Draw CT tangent to this arc. Construct a perpendicular to CT, passing through C. Does this line coincide with CH?

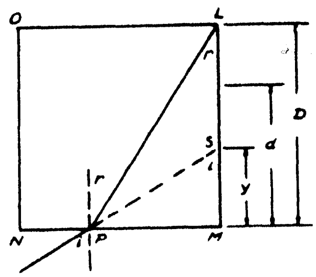

Figure 4

Part 3

Study Figure 4. Express Snell's Law in terms of the symbols in the figure. Show that in the limit, as i and r both approach 0, and y approaches d, the apparent depth, that

$$\mu = D/d.$$

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Observations, Drawings, Computations: ______

Answers and Conclusions: ______

TEST EXPERIMENT 28

1. An object a....cm. below the surface of a liquid appears to be b....cm. below the surface to an observer directly above the object. The index of refraction of the liquid is (1) , (2) , (3) , (4) . . . . ( )

2. The frequency of yellow light in air is a....cycles per second. In glass whose index of refraction is b...., the frequency (in cycles per sec.) will be (1) , (2) , (3) , (4) , ( )

3. The index of refraction of glass with respect to air is a.... Hence the velocity of light (3×10^{10} cm./sec. in air) in glass (in cm./sec.) is (1) , (2) , (3) , (4) . . . . . . ( )

4. If a beam of light has a....waves per cm. in air, it will have in water (index of refraction b....) (1) , (2) , (3) , (4) waves per cm. . . . . ( )

5. The absolute indices of refraction of substances 1 and 2 are a.... and b....respectively. Hence the relative index of substance 1 with respect to substance 2 is (1) , (2) , (3) , (4) . . . . ( )

6. The velocity of light in air is approximately 3×10^{10} cm./sec. The index of refraction of a substance in which the velocity of light is b....cm./sec. is (1) , (2) , (3) , (4) . ( )

7. The apparent depth of a stream is a....ft. Actually the depth (in ft.) of the water (index of refraction is 4/3) at that point is (1) , (2) , (3) , (4) . . . . ( )

8. If a light source is placed a....ft. below the surface of a pool of water (index of refraction is 4/3), the light emerging from the surface will be limited to a circle whose radius (in ft.) is (1) , (2) , (3) , (4) . . . . ( )

9. A layer of water (index of refraction 4/3) a....cm. thick is supported by a glass slab (index of refraction 3/2) of the same thickness. If a coin is placed under the glass slab, the apparent depth of it to an eye looking directly down is (in cm.) (1) , (2) , (3) , (4) . . . . ( )

10. The velocity of light in substance 1 is a....cm./sec. and the velocity in substance 2 is b....cm./sec. The index of refraction of substance 1 with respect to substance 2 is (1) , (2) , (3) , (4) . . . . ( )

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Observations, Drawings, Computations:

Answers and Conclusions:

The following convention of signs is used in equations (5) and (6):

Focal length, f, is positive for converging lenses and negative for diverging lenses.

Radius, r_1 or r_2, is positive for convex surfaces and negative for concave surfaces.

Object distance, p, is positive when the object is real and negative when it is virtual.

Image distance, q, is positive when the image is real and negative when it is virtual.

Experiment

Part 1

Positive Lens --Put the spherometer pegs on the plane surface of the lens and adjust the micrometer screw until the central point just touches the surface of the lens, and then read the scale. Then place the pegs on the surface of the lens to be measured and adjust the micrometer screw until the central point just touches the surface of the lens and again read the micrometer scale. The difference in the two readings gives the distance marked S in Figure 2. The radius of the circle determined by the three pegs is denoted by y. Measure the distance from the central point to each peg, and take the average value for this distance y. Calculate the value of r_1, the radius of curvature of the spherical surface of the lens. The other surface of the lens is plane and has a radius of curvature equal to infinity.

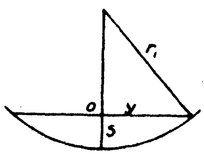

Figure 2

Calculate the focal length of the lens from equation (5) using $\mu = 1.53$.

Put the lens on an optical bench and get a good clear image on the screen. Measure the object and image distances from the proper equivalent planes. (See the Instructor).

Calculate the focal length from the standard lens formula:

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f} \quad . \tag{7}$$

Tabulate data and results for both cases.

Part 2

Negative Lens.--Find the focal length of a negative lens from the constants of the lens in the same way as in Part 1.

Use the positive and negative lens in combination to find the focal length of the negative lens with the optical bench. The lenses are tied together with a tie-rod so that the positive lens is next to the object.

Fix the lenses on the bench as described and get a clear image on the screen when the object is about 60 cm. from the first lens. Measure this distance, also the distance from the image to equivalent emergent plane of the second lens, and the distance between adjacent equivalent planes of the lenses as in Figure 3.

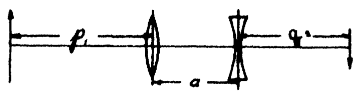

Figure 3

From the focal length of the positive lens found above and the values of p_1, a and q_2, calculate the focal length f_2 of the negative lens. Tabulate data and results for both cases of Part 2.

Name: ______________ Instructor: ______________ Division: ________ Date. ________

Observations, Drawings, Computations: ______________

Answers and Conclusions: ______________

TEST EXPERIMENT 29

1. A convex lens of a...cm. focal length forms a real image at b....cm. The object is at a distance (in cm.) from the lens of (1) , (2) , (3) , (4) . . . . ( )

2. A double convex lens whose curvatures are a.... and b....deg. per cm. is made of glass of refractive index c.... The focal length of the lens is (in cm.) (1) , (2) , (3) , (4) . . ( )

3. A real image is a....cm. from the object. If the magnification is b...., the focal length of the lens (in cm.) is (1) , (2) , (3) , (4) . . . . ( )

4. A virtual image is a....times as large as its object and the two are b....cm. apart. The focal length of the lens (in cm.) is (1) , (2) , (3) , (4) . . . . ( )

5. A virtual image is a....times as large as its object. The focal length of the lens is b....cm. The distance between object and image (in cm.) is (1) , (2) , (3) , (4) . . ( )

6. The distance between the moon and the earth is approximately 385,000 kilometers. The diameter of the moon is about 3600 kilometers. The image of the moon formed by a lens of a.... meters focal length will have a diameter (in cm.) of (1) , (2) , (3) , (4) . . . . ( )

7. A camera lens has a focal length of a....inches. If one wants to photograph a person b....ft. away from the camera, you must place the photographic plate behind the lens at a distance (in inches) of (1) , (2) , (3) , (4) . . . . ( )

8. An object is a....cm. from the convex lens of a convex-concave lens combination. If the lenses are b....cm. apart and the focal lengths of the concave and convex lenses are c....cm. and d....cm. respectively, then the final image is formed at a distance (in cm.) from the concave lens of (1) , (2) , (3) , (4) ( )

9. A lamp and screen are a....ft. apart. To get an image on the screen a converging lens with focal length of b....ft. must be placed a distance (in ft.) from the lamp of (1) , (2) , (3) , (4) . . . . ( )

10. Using a spherometer to find the radius of curvature of a lens surface, the sagitta was found to be a....mm. and the distance between central and outside legs b....cm. The radius (in cm.) is (1) , (2) , (3) , (4) . . . . ( )

Name: ______________ Instructor: ______________ Division: ________ Date. ______

Observations, Drawings, Computations: ______________

Answers and Conclusions: ______________

Experiment 30

TELESCOPES

Object:

To study the lens construction and the magnifying power of several types of telescopes.

Apparatus:

Optical bench, two positive lenses, one negative lens, one plane glass with cross hairs, one white screen.

Theory:

The two types of telescopes in common use are the Galilean telescope, and the astronomical or laboratory telescope.

The Galilean Telescope consists of a positive lens O of comparatively long focal length known as the objective (nearer the object) and a negative lens E of shorter focal length known as the ocular or eyepiece. In practice the ocular is frequently made up of a combination of lenses, but we shall treat it as a simple lens in order to simplify calculation.

The magnifying power of a telescope is defined as the ratio of the angle subtended at the eye by the image formed by the telescope to the angle formed by the object.

Consider Figure I. The two rays from the left are coming from the top and bottom of the object AB and since the length of the telescope is small compared with the distance to the object, α measures the angle at the eye subtended by the object. These two rays move toward the right and tend to pass through the end point of A'B' in the focal plane of the objective lens.

α then is measured by

$$\frac{A'B'}{f_1} = \tan \alpha$$, where f_1 is the focal length of the objective.

Consider now the ray X which is chosen from among those tending to form the image at the point B' because it is parallel to the principal axis of E. It leaves E, therefore, as though it had passed through F_2. But obviously it comes from the point B since it tended to form the image of B at B'. Y is a corresponding ray from A. The angle between these two rays as they leave lens E is then the angle β and is measured by

$$\tan \beta = \frac{A'B'}{f_2},$$

where f_2 is the focal length of the eyepiece.

(Note: The rays drawn do not locate image A"B" but one knows that A"B" will be somewhere along these lines and hence the image A"B" as seen at E subtends the angle β at the eye.) For most easy vision the image A"B" will be at ∞ toward the left.

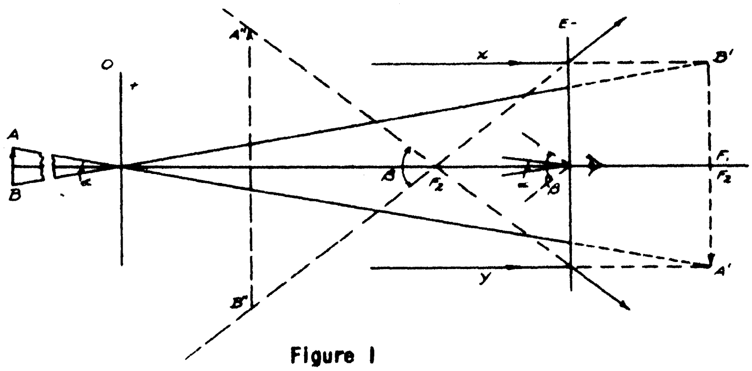

Figure I

$$\text{Mag.} = \frac{\frac{A'B'}{f_2}}{\frac{A'B'}{f_1}} = \frac{f_1}{f_2} .$$

The Astronomical Telescope (Figure 2) is made up of an objective lens of long focal length and an ocular, also positive, of considerably shorter focal length. The objective causes a real inverted image A'B' of the object to be formed between the two lenses. The ocular is placed so that the light which diverges toward the right from this real image will leave it parallel. Thus the distance between the two lenses focused for a distant object will be equal to the sum of the focal lengths. The Astronomical Telescope forms an inverted image of the object.

The magnifying power is again calculated by

$$M = \frac{f_1}{f_2} .$$

Name: ______________________ Instructor: ______________________ Division: __________ Date. ________

Observations, Drawings, Computations: ______________________

Answers and Conclusions: ______________________

TEST EXPERIMENT 30

1. The moon subtends an angle of a....minutes at the eye. In a telescope which magnifies b....times, the angle that the image would subtend at the eye would be (1) , (2) , (3) , (4) . . . . ( )

2. The magnifying power of an astronomical telescope is a... The focal length of the objective is b....in. The length of the telescope is (in inches) (1) , (2) , (3) , (4) . . . . . . ( )

3. An astronomical telescope has lenses of focal lengths a....cm. and b....cm. In order that the cross hairs may appear to be in coincidence with the image seen in the telescope, they should be placed at a distance from the objective equal (in cm.)to (1) , (2) , (3) , (4) . . . . ( )

4. An astronomical telescope is focused on an object a....cm. from its objective so that the light emerging from the eyepiece is parallel. The focal lengths of the objective and eyepiece are b.... and c....cm. respectively. The distance between the two lenses is (in cm.)(1) , (2) , (3) , (4) . . . . . . ( )

5. In an astronomical telescope the focal length of the ocular is a....cm. The distance between the lenses is b....cm. The magnifying power is (1) , (2) , (3) , (4) . . . . . ( )

6. In a Galilean telescope the objective has a focal length a....times the distance between the lenses. The focal length of the ocular is b....cm. The focal length of the objective(in cm.) is (1) , (2) , (3) , (4) . . . . ( )

7. A Galilean telescope is focused on an object a....cm. from its objective so that the eye sees the image 25 cm. in front of the eye lens. The focal lengths of the objective and eyepiece are b....cm. and c....cm., respectively. The distance between the two lenses (in cm.) is (1) , (2) , (3) , (4) . . . ( )

8. An astronomical telescope and a Gallilean telescope both have objectives of focal length a....cm. and a magnifying power of b.... The Galilean telescope is shorter than the astronomical telescope by a distance in cm. of (1) , (2) , (3) , (4) . . . . . ( )

9. The focal lengths of the objective and eyepiece of an astronomical telescope are a....cm. and b....cm. respectively. When a distant object is viewed, the two lenses are a distance c....cm. apart. The image appears at a distance(in cm.) from the eyepiece of (1) , (2) , (3) , (4) . . . . ( )

10. The magnifying power of a Galilean telescope is a.... and its length is b....cm. The focal length of the objective lens (in cm.) is (1) , (2) , (3) , (4) . . . . ( )

Name: ______________________ Instructor: ________________ Division: ______ Date. ______

Observations, Drawings, Computations:

Answers and Conclusions:

Experiment 31

THE PLANE DIFFRACTION GRATING

Object:

To beoome acquainted with the diffraction grating and to use the grating to measure roughly the wave length of light.

Apparatus:

Plane transmission grating, single slit, source of light, scale and optical bench.

Theory:

"Huyghen's Principle" (each point on an advancing wave front acts as a new center of disturbance from which secondary waves originate) is to be applied to the diffraction grating.

A diffraction grating is made by ruling parallel lines on a plane piece of glass or other material so that the distance between adjacent lines is constant.

If a slit source of monochromatic light is observed through a grating we see not only the source slit in its actual position, but also diffracted images of it. According to the principle of interference every diffracted wave front advancing from the grating must make an angle θ with the grating such that

$$\frac{n\lambda}{s} = \sin \theta ,$$

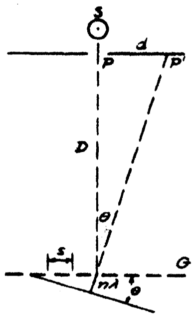

Figure 1

where λ is the wave length of the light and s the distance between the lines on the grating and n is an integer (known as the order of the diffracted image). The direction of motion is perpendicular to the wave front, and so the disturbance due to a wave front at an angle θ to the grating will apparently come from a point P' a distance d from the source slit P, where $\frac{d}{D} = \tan \theta$ if D is the distance between the slit and the grating. If d and D are measured, θ can be found and calculated,

$$\frac{n\lambda}{s} = \sin \theta ,$$

$$\lambda = \frac{s \sin \theta}{n} .$$

Experiment

Part 1

With the apparatus arranged as shown in Figure 1 note the position on the scale of as many lines as possible. For the first order n = 1, for the next n = 2, etc. Measure d and D for each line, and calculate s from the number of lines to the cm. on the grating. Calculate λ for each case and arrange in the table.

n	D	d	tan θ	θ	sin θ	λ cm.
1						
2						
3						
4						
5						

Part 2

Repeat for two more values of D.

Part 3

Determine the average value of λ from all of your measurements.

Name: Instructor: Division: Date.

Observations, Drawings, Computations:

Answers and Conclusions:

TEST EXPERIMENT 31

1. The frequency of a mercury violet line for which the wave length is a....cm. is (in vib./sec.)(1) , (2) , (3) , (4) . . . . ( )

2. The wave length which forms a first order image at a....deg. to the main beam when transmitted by a grating of b....lines to the cm. is (in cm.) about (1) , (2) , (3) , (4) . ( )

3. In problem (2) if the distance from the screen to the grating is a....cm., the distance from the spectral line (whose wave length was to be calculated) to the direct beam is (in cm.)(1) , (2) , (3) , (4) . . . . ( )

4. The wave length of green light is a....cm. The first order of this spectral line would be diffracted by a grating with b.... lines per cm. at an angle of (1) , (2) , (3) , (4) . ( )

5. The first order of a certain wave length is seen at an angle a.... The second order will appear at an angle b....given by (1) , (2) , (3) , (4) . . . . ( )

6. The first order green line of mercury (wave length is a....cm.) is seen at b....deg. to the main beam from the slit. The number of lines per cm. on the grating is about (1) , (2) , (3) , (4) . . . . ( )

7. The a. ..th order image of a line of wave length b....cm. coincides with the c....th order image of a line of wave length(in cm.) of (1) , (2) , (3) , (4) . . . . ( )

8. The wave length (in cm.) corresponding to a frequency of a....vib. /sec. is (1) , (2) , (3) , (4) . . . . ( )

9. The grating space (in cm.) of a grating which produces an a....th order image at an angle of b....deg. is (1) , (2) , (3) , (4) . . . . ( )

10. A grating with a....lines to the cm. forms an image of a line of wave length b....cm. at an angle whose sine is c.... The order of the image is (1) , (2) , (3) , (4) . . . . ( )

Name: ______ Instructor: ______ Division: ______ Date. ______

Observations, Drawings, Computations: ______

Answers and Conclusions: ______